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COMPUTER AID ASSESSMENT OF DRIVER'S FATIGUE DURING DRIVING BASED ON EYE MOVEMENTS ANALYSIS

In the article a specific biomedical requirements for the driver's psychophysical condition in terms of early warning system against excessive fatigue states was presented. In the first part of the paper selected driver's biomedical parameters were described, next the video image analysis algorithms in the context of eye movements were presented. In the last part a hardware solution for the non-invasive on-line measurements was proposed and the results obtained in practice were briefly characterized.

1. INTRODUCTION

The problem of detecting a driver's fatigue is a complex issue, which is the subject of researches of many scientists. Given the fact that limitation of psychophysical fitness causes disorder at decision and perception processes, it can be considered as a major cause of road accidents [11]. Already in the sixties in the U.S. efforts to create a system to prevent and respond to occurring symptoms of concentration loss have been made. Simple monitoring systems, which analysed the position of the head, controlled the hands' position on the steering-wheel or the position of auxiliary pedals were made [4]. The current researches on driver's fatigue are going towards non-invasive biomedical measurements that reliably reflect the level of a driver's psychophysical conditions. The studies base primarily on analysing of the driver's face area using methods of digital images processing and object detection.

2. BIOMEDICAL INDICATORS OF DRIVER PSYCHOPHYSICAL EFFICIENCY

The driver's psychophysical efficiency is the level of the ability to drive a car, which results directly from the driver's psychological and physiological condition. Many factors affect the driver's psychophysical efficiency, such as: monotonously driving, driving for a long time, noise in the cabin, vibrations or increased traffic. These factors contribute to reduction of visual-movement coordination, lengthening the reaction time, aggravating concentration that leads directly to extension of the risk of causing a dangerous situation on the road.

Current researches focus on a variety of methods for assessing a driver's fatigue, starting from the external monitoring driving parameters, such as direction, turn, speed, longitudinal and transverse acceleration and ending on controlling the driver's psychophysical parameters. For the driver's physiological state assessment researches of measuring the brain waves activity (EEG), cardiovascular system (EKG), galvanic skin response (GSR), location and control of the head movements or activities of the eyes are applied.

The measurement of the brain waves activity (EEG) is considered to be one of the most reliable indicators of the driver's psychophysical fitness condition and in particular in drowsiness periods while driving detection [4]. Authors ([19],[2],[5]) stress the possibility of detecting dangerous states of limited vigilance and lapses of attention basing on the EEG spectral analysis.

Continuously monitoring the electrical activity of the heart (EKG holter monitor) allows to assess the cardiovascular driver's system while driving. The carried out studies confirmed the correlation of cardiovascular system disorders with a high probability of the occurrence of a traffic accident [17] and proved that a change of the pulse is a reliable trace of the driving monotony

Measuring the galvanic skin response (GSR) is detecting the resistance of the skin under the influence of the exuded sweat. This reaction arises indirectly as a result of sympathetic nervous system activity, which, according to the authors, appears to be another symptom of the driving monotony and the driver's weariness [18].

The control of the head's location and movements might be useful, due to the fact that the speed and the range of the driver's head movements alter their value under the influence of the driver's fatigue. What is more, as a result of drowsiness, the head may tend to bob or drop or roll [3], becoming a critical symptom of a dangerous state of limiting the driver's psychophysical fitness condition.

The estimation of the eyes activity bases on the designation of the eyes mobility (horizontal and vertical movements) as well as on the frequency and periods of eyelid blinks. Furthermore, the control of the visual field and the observation of immovable points such as windshield or mirror is performed. The obtained results of the studies ([4],[3]) suggest that a parameter defined as PERCLOS (percentage of time during which the eye is closed over 80%) has a very big significance. The authors clearly show that this parameter is the most credible and reliable factor of the driver's fatigue assessment.

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In the opinion of the authors, taking into account non-invesiveness, and the availability of hardware solutions, it is desirable to draw attention to the latter of these methods of assessing the driver's fatigue and in particular to the parameter which characterises the degree and the period of the eye closure.

3. THE ANATOMY AND PHYSIOLOGY OF THE EYE

The vision is the most important sense for most people. The human eye, that is an “interface” between the environment and the brain, has an approximately spherical shape with a radius of about 24mm [13].

The external, visual parts of the eye are the sclera, the iris and the pupil, which is located in the centre of the iris (fig. 1). The visual region of the eyeball is approximately 25-30 mm wide, and 10-12 height [14]. This region depends on the gap between eyelids and it changes during blinking. The average pause between blinks is individually differential and lasts about 2,8s (men) or about 4s (women). The duration of one full blink is about 0,3-0,4s [1].

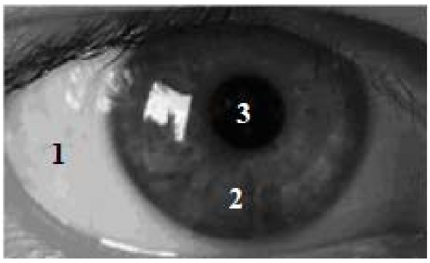

Fig. 1. The visual part of the eye (1 – sclera, 2 – iris, 3 – pupil)

The human eyes move permanently. They stop only for very short moments (200-300ms), when the gaze is focused on one point. This state is called fixation. After image processing, the eye moves rapidly to another point. Those rapid movements are termed saccades. Besides fast movements, the eyeball can rotate in about 70° in every direction.

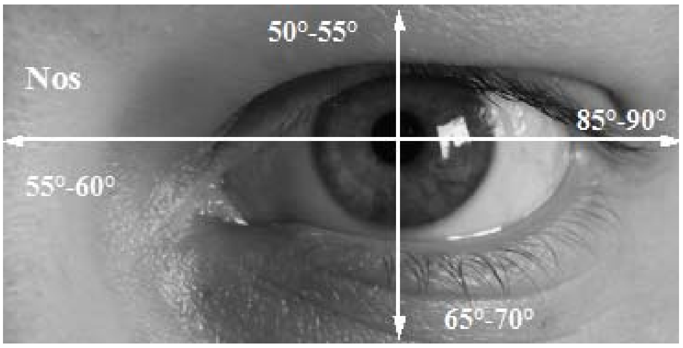

Fig. 2. The visual field of one eye [13]

The visual field of one eye is a space that is perceived by a fixed eye with immobile head [14]. The average visual field for each eye is presented on the fig. 2. The size of this region is individually differential and depends on the eye’s inset depth.

4. SPECIFICATION OF THE DEVICE FOR DRIVER IMAGE ACQUISITION

In the previous section the most important properties of the human eye in the context of judgment of a driver's state while driving was described. Below an analysis of the device’s requirement, that will be used for image recording of the driver’s face is presented. Basing on this image, the examination of the driver’s eyes’ region will be possible. The eye’s region on the image must be large enough to calculate important coefficients. Therefore, it is required to compute the size of the camera’s recorded area at the distance where the driver’s head is located.

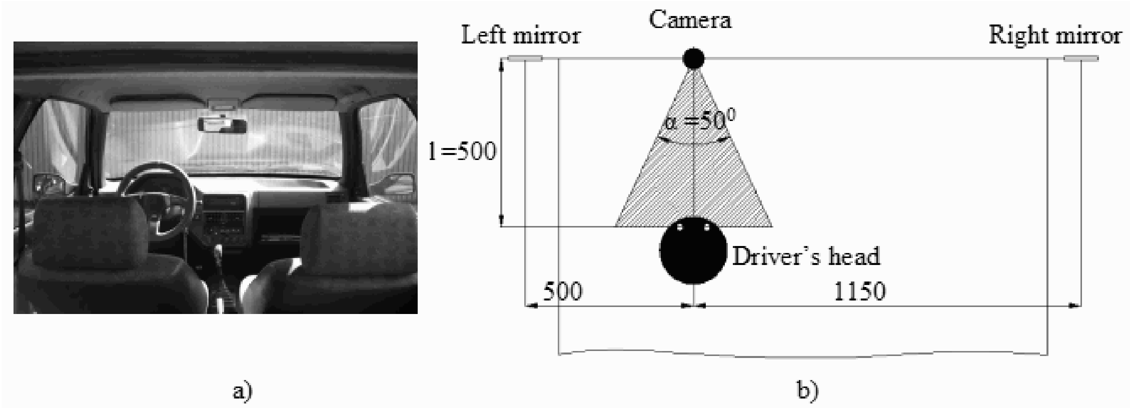

Fig. 3. The car's interior a) and the camera's localization b).

The interior of a typical car is presented on fig. 3. The driver's head is at the distance *l* from the front windscreen of a car, the visual angle of a digital camera is marked as α. The size of the camera's recorded area can be express using the following expression:

$$w = 2 * l * tg(\alpha / 2), \quad (1)$$

where: *w* – width of the camera's recorded image at the distance *l, l* – distance from the driver's head to the camera, *α* – camera's visual angle.

On fig. 4 an auxiliary picture for equation (1) is presented.

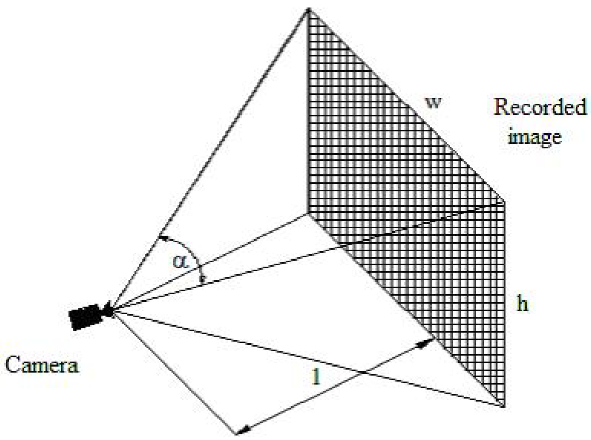

Fig. 4. The size of the camera's recorded area

The aspect ratio of the camera's recorded image is 4:3. Thus, the height of an image is:

$$h = \frac{3}{4} w, \quad (2)$$

where: *w* – width of the camera's recorded image at the distance *l,* h – height of the camera's recorded image at the distance *l,*

Assuming, that the distance *l* is 500mm and the typical value of the widely available digital camera's visual angle is 50°, the size of the recorded image is about 466 by 350 mm.

As mentioned before, the visible region of the human eye is approximately 25 x 10mm, and the eyeball's rotation range is 70°. In order to track the eye movement with accuracy of about 1°, it is required that the eye's region on the image is about 70 pixels. It means that the input image size should be 1280x960 pixels. At this moment, there are only few widely available (in terms of price) digital cameras that offer video capturing with such quality. Moreover, the huge amount of data, which has to be process, might be a serious problem. Currently available web cams capture images that have 640x480 pixels. For this resolution the size of an eye image is 27 x 14 pixels, so the eyeball's movement can be tracked with an accuracy of about 2,5°. Higher resolution e.g. 960x720 allows tracking with accuracy of about 1,5°.

5. ALGORITHMS FOR EYES/FACE DETECTION

It is possible to judge the driver's state by the activity of his eyes, and his face position. In order to do this it is necessary to extract the driver's face and eyes region from the image. This issue is very complicated because of image inconstancy due to the changing light condition or observation angle. Furthermore, improper colour, brightness or texture of the background can make even the automatic face and eyes detection process completely impossible.

In the last few years the problem of face as well as eye detection was frequently discussed in literature. Many different approaches to this problem was developed, some of them are basing on simple image processing to search for the regions with a colour similar to the skin's one [15], others are using neural networks [16] or statistical classifiers [7]. An exhaustive survey of current face detection methods was presented in [21]. Most of them, besides many advantages, have one, fundamental for the problem described in this paper, disadvantage: high computational complexity. This fact causes, that the mentioned solutions are useless in on-line analysis of the driver's state.

Viola and Jones have presented in [20] a framework for fast object detection in images, in particular the face. This framework consists of few components, which form an extremely efficient tool.

The idea of this approach is based on so-called integral image, which is a different representation of the image. Every single point of the integral image contains a value, which is a sum of intensities of all the pixels above and to the left of the given point, inclusive:

$$ii(x,y) = \sum_{x' \le x, y' \le y} i(x',y'), \qquad (3)$$

where: $ii(x,y)$ – integral image, $i(x,y)$ – original image.

Using such representation of an image, it is possible to efficiently calculate features reminiscent to Haar basis functions. The examples of features used by Viola et al. are presented on the picture below (fig. 5).

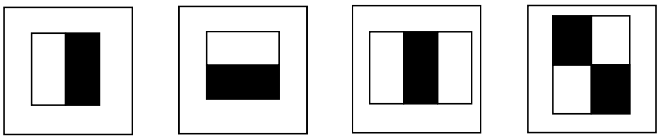

Fig. 5. The examples of the features

During the learning process the most significant features are selected. At this stage, most of the earlier computed features are excluded (the number of the features is far larger than the number of pixels), thanks to that the objects' detection is significantly accelerated. To calculate the best features, the AdaBoost algorithm is used, which creates the weak classifiers. Every weak classifier depends only on one feature.

Weak classifiers are combined to form more and more complex classifiers, creating a cascaded structure. Particular sub-windows of the image are examined with the least complex classifier (the first element of the cascade). In case of positive verification, a given sub-region is being processed with more complex classifiers (fig. 6). Thanks to such approach, it is possible to select regions, where an object might occur, without processing expensive computation of the whole image.

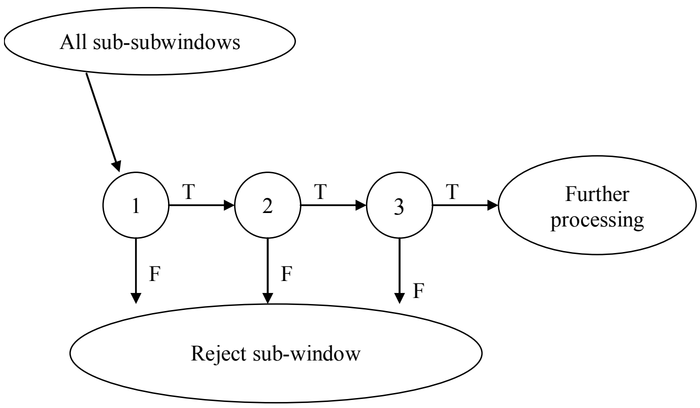

Fig. 6. The schema of the cascaded objects' detection

Viola et al. reported, that using this method and operating on a 384 by 288 pixel image, they detected objects at 15 frames per second, with quite high accuracy of about 90%.

The presented solution has become a base for further researches and modifications. Lienhart et al. [7] have presented a new kind of features and compared three versions of the AdaBoost algorithm. They have stated that 45° rotated features increased detection's speed and accuracy. In [4] another modification of features set has been presented, that allows creating a reliable eyes' detection algorithm.

In the opinion of the authors, the Viola&Jones algorithm with later modifications is a perfect solution for on-line analysis of the driver's state, due to its speed and accuracy and it will be used in current researches.

6. RESULTS

Within the confines of the authors' researches, the video image of a driver during the driving was recorded. The image was captured in resolution of 640 by 480 pixels, 30 frames per second. Basing on this material, the face region as well as the eye region can be extracted. What is more, high frame rate allows to observe parameters such as head motion, eye motion and blinking.

On fig. 7 images of a single blink are presented. It can be noticed, that the full blink was registered on 10 frames. It means that one blink lasted for about 1/3 second, which is similar to the values presented in section 3.

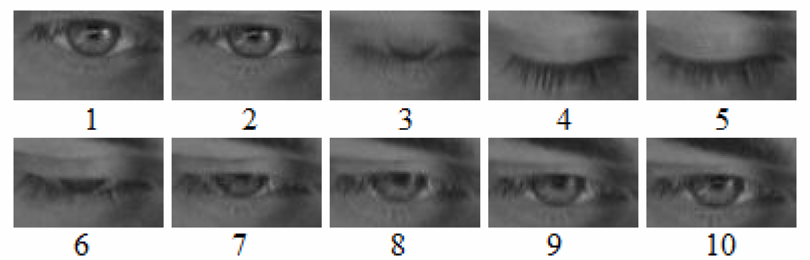

Fig. 7. Images of the eye during blink

On the next figure (fig. 8) images showing an eye movement are presented. It can be seen, that till frame 5 the eye moves in one direction, then in frames 8-13 it moves in the vertical dimension, and at the end it returns to the starting position. Taking under consideration the first five frames it can be affirmed, that the eye movement lasted for 1/6 second, the linear velocity (assuming eye's visual region of 25mm wide) is $v = \frac{0{,}013\,m}{0{,}16\,s} = 0{,}81\,{}^{m}\!/_{s}$, and the value of angular velocity is $\omega = \frac{0{,}61\,rad}{0{,}16\,s} = 3{,}81\,{}^{rad}\!/_{s}$ (assuming eyeball's rotation range about 70°).

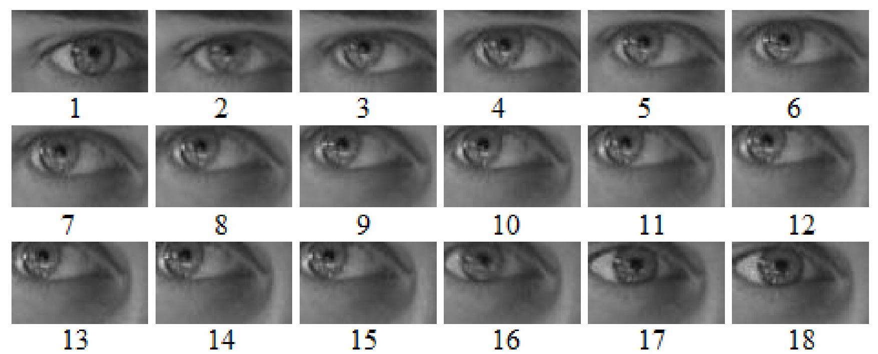

Fig. 8. Images of the moving eye

By analysing the sequence of images it might also turn out, that a visible change of the dynamic of the head movement could be in correlation with the level of a driver's fatigue and the driving time.

7. CONCULIONS AND FUTURE WORKS

The presented analyses and results give a solid base to build a system for estimation of a driver's psychophysical condition. In a consequence of combining digital image processing methods and biomedical factors (selected on the basis of literature studies), a reliable tool for monitoring the state of a driver's fatigue is obtained.

In order to increase the speed and efficiency of digital data processing, it is planned to modify existing objects' detection algorithms in future works, to efficiently support the process of factors evaluation, which are interesting from the point of view of the presented problem.

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