Recognition of the Human Fatigue Based on the ICAAM Algorithm

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Abstract. The international statistics show that a large number of road accidents are caused by driver fatigue. A system that can detect oncoming worker fatigue could help in preventing many accidents. Many researchers focused to measure separately different physiological changes like eye blinking or head movement. Uncomfortable EEG analysis is also discussed in this field. In presented paper, we describe a simple, non-intrusive system for detection of worker fatigue. The system, based on Inverse Compositional Active Appearance Models (ICAAM) method, allows for comprehensive analysis of the face shape and its basic elements.

Keywords: Fatigue detection · Worker fatigue · ICAAM · Yawning · Eyes blinking

1 Introduction

Fatigue is one of the most important factors determining the performance and safety on a variety of workplaces. Overall fatigue is the most frequently mentioned work-related problem, and even more so for transport workers [1]. Statistical data summarizing the accidents are very sad. Drivers and doctors (surgeons) are professions where the dangerous consequences of fatigue can be very serious. In many countries tiredness and falling asleep while driving was found to explain almost 20 % of the traffic accidents causing deaths [2]. Symptoms and effects of fatigue are obviously dependent on individual predisposition and age. It depends also on the time of day or night, and the circadian cycle of work and rest. Early and fast recognition of fatigue can prevent accidents in many cases. In addition, identification and assessment of fatigue can be used in many scientific fields.

The aim of this study was to develop a simple and effective system for fatigue detection based on facial image analysis. Additionally the usefulness and implementation possibility of Active Appearance Models (AAM) and Inverse Compositional Active Appearance Models (ICAAM) methods in extracting facial features needed to assess the fatigue were analyzed.

Rapid technological development causes, that attempts to auto-evaluation of the multivariate condition (and thus also the fatigue) are increasingly being used in various fields. A good example is the automotive industry, where the newer types of cars

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are equipped with a variety of sensors and driver assistance systems. Attempts to detect fatigue in such systems are based on the analysis of driver activity. Most often analyzed are: the driver's eye movements and the timing and frequency of eyelid closure [3] or the physical activity (movements of the body, hands, facial muscle movements) [4]. Despite the fact that work on the described technology have been carried out for more than 10 years, it still imperfections of such solutions and the complexity of the problem does not allow to put it into the mass (inexpensive and commonly used) production.

Fatigue tests for detection are carried out in different directions. In many papers eye tracking system is used for detection of sleep symptoms [5,6,7,8,9]. Devi and Bajaj [5], focused on the state of eyes (open or closed) in 5 consecutive frames of video. In [6] blinking analysis (frequency and duration) was used and also the Karolinska Sleepiness Scale (KSS) was discussed.

Singh and Papanikolopoulos in paper [8] determine driver fatigue by analysis of eyes movements and looking for micro-sleep symptoms. The yawning analysis can be added effectively to the eye tracking [10]. In the paper [11] the authors try to use global analysis of the physiological state of fatigue, but in order to achieve real-time performance they focused on a single visual cue – the state of the eye. In [12] a Support Vector Machine (SVM) classifier is used. It allows recognize the state of fatigue in the face image after proper SVM training. EEG analysis has been also used in detection the level of sleepiness [13,14,15]. There is very interesting method but in our opinion it is today unpractical in a real work of drivers. We can find also well prepared surveys of the fatigue and sleep symptoms [6], [16,17]. Very interesting example of the review is the industrial publication [18] where the set of systems for detecting fatigue in the mining industry has been described.

2 Behaviors That Demonstrate the Appearance of Fatigue

Recognizing of the fatigue and sleep symptoms is the important tasks of psychology of work. Research on a sleep is conducted by the National Sleep Foundation [19]. It is nonprofit organization whose stated objectives are not only to focus on comfort of the sleep but also to improve public health and safety in context of sleep problems. When we analyze the behavior of human fatigue, we should focus on the three main parts of the face (eyes, eyebrows, mouth) and the whole head [19]. Most of the fatigue recognition systems use one selected item of the face. Most often it is the analysis of eye movement / blinking. It should be noted, however, other factors, including the impact of working / activity time. The impact of sleep deprivation on skill based cognitive functions and the degradation of performance of responding to unexpected disturbances was also analyzed in the literature [20].

The most important items that indicate changes of the fatigue level include:

- **The eyes.** It stands out, mainly, a smaller opening of the eyelids and increased frequency of eye blinking. In addition the movements of the eyelid (blinking), in this case, become much slower than those in the state of the rest. Attention should also be paid to the viewing direction. While the state of fatigue, people often look for a long time at one point, it is the so-called state of "suspension".

- **The mouth.** The basic and reliable response of the mouth, which proves fatigue, is yawning. Assuming that the default position is closed or slightly open mouth, it is enough to analyze the opening of the upper and lower lips. In addition, it is worth noting that while yawning, in the moment of maximum mouth opening, a person also frequently closes his eyes and frowning.
- **The eyebrows.** Eyebrows are closely related to human eyes. Rested man performs small movements of the eyebrows in accordance with the movements of the eyes (eyelids). Fatigue causes "stillness" of the eyebrows.
- **The head.** The behavior of the head is also important. Tired man has difficulty keeping his head straight and vertical. In the final stage of fatigue (and indeed at the moment of falling asleep), the head falls forward or deviates far to the rear or to any side. Tired person starts also more likely to touch his face, as well as over-comb his hair.

It is worth noting that all behaviors mentioned above can be analyzed in a similar manner using methods of shape recognition for the face.

3 Image Processing in the Fatigue Detection

Separation of facial features can be performed using multiple algorithms. Frequently used method for analyzing medical or mechanical images, as well as images of the face is an Active Shape Model (ASM) [21,22]. In this method, the shapes are described by a set of so-called landmark points. In the learning phase, a statistical model is constructed for a given object. In the recognition phase the attempt is made to match the analyzed object model. The combination of using the Active Appearance Models (AAM) [23] allows additionally analyzing the texture. Statistical models of shape and appearance are powerful tools for interpreting medical images. We assume a training set of images in which corresponding landmark points have been marked on every image. From this data we can compute a statistical model of the shape variation, a model of the texture variation and a model of the correlations between shape and texture [24]. AAM is an iterative algorithm, the iteration followed by matching shapes to the shape of the reference. Inverse Compositional Active Appearance Models (ICAAM) [25] is an improved version of the AAM algorithm.

ICAAM method was used in the proposed solution in this article. Analysis is performed using images captured by a video camera. On the face from the image the grid points was applied to describe the shape. Tracking changes in the position of the grid points allows us to analyze changes in the shape of the face, and thus analyze the changes of the shape and position of the individual face elements. In accordance with Chapter 2 changes recognized as closing eyes and yawning are taken into account. The analysis of the relevant changes leads to attempt of fatigue detection.

The main problem of facial image processing for detecting fatigue is to identify the appropriate shape of the lips. The main difference between yawning and standard mouth that is in open state is that the yawning state is recognized based on time. Our algorithm checks if the distance between mouth upper and lower lips is greater than width of the mouth. Based on the landmark points the maximum width and height of mouth is calculated in each iteration. That gives us the accurate comparison parameters. When the correct criteria for yawning are met, algorithm starts tracking how long yawning is taking. Fatigue level increases more with time. It means that more fatigue points will be added to the overall fatigue level for example in the 3rd second of the yawning than in the first second. That gives us nice advantage against faulty recognition when human just open his mouth to speak something. Even if criteria are met (distance of the lips higher than width of the mouth), this state will last for very limited period of time, that means it will not impact overall fatigue level in the meaningful way. This same rules are applied when algorithm track eyes. Both eyes, at the same time need to be in a closing state. The distance between upper and lower eyelid needs to be equal or lower than one of the third of width of the eye. And again maximum height and width of the eye are calculated in each recorded frame.

4 Assessment of the Fatigue Condition

In order to facilitate the final evaluation, the simple percentage measure of fatigue has been proposed. We assume that the initial level (initial measure) of the human fatigue is 0%. Along with the ongoing tracking and analysis the level of fatigue may rise or fall. But it will be always situated in the range from 0% to 100%. In the algorithm, the different weights for individual events have been used. We proposed simple formulas (1), (2) describing the changes of the fatigue condition in the best way.

For increasing the fatigue level:

$$CFL = CFL + 0.5(LEC + REC) + 0.75MO \tag{1}$$

For reducing the fatigue level:

$$CFL = CFL - \frac{\sqrt{ET}}{ET} \tag{2}$$

where:

CFL - current fatigue level (in percent 0-100%), *LEC* - left eye closed, *REC* - right eye closed, *MO* - mouth opened, *ET* - elapsed time when no single fatigue symptoms were detected (in seconds). The values of *LEC*, *REC* can be: 0, 1, 2, 3, etc. – in proportion to the time of closing eyes in seconds. The value of *MO* can be 0 or 1.

At the start of analysis *CFL*=0 . After every change of fatigue level, the value of *CFL* is corrected if it is out of the range (0-100).

The formulas (1) and (2) were developed empirically. We performed set of experiments and many versions of the equations were analyzed. The main idea behind this equation was that single evidence of fatigue detected from eyes is greater than single evidence detected from mouth. However this is only valid when both eyes are closed with the given criteria. That means when only one eye is closed the fatigue level will increase less dynamically than when yawning is detected. But when both eyes are closed, fatigue level will increase more rapidly than during yawning. Of course all the value parameters can be adjusted for the further experiment purposes. Current values were giving the best results for the experiments performed on the face database. During the time that algorithm doesn't detect any symptoms of fatigue; the overall level of fatigue is decreased. But it's decreasing a lot slower than it can increase when fatigue symptoms are detected.

The rules of "fatigue behavior" (described above) are simple and obvious but not so easy to describe by simple equation. Many versions of equation with different weight were taken into account. To find the right weight for individual events and provide the best work of the algorithm many trials and comparative studies have been conducted.

5 Implementation and Tests of the System

The project was written in XCode and Qt-Creator environment for MacOS X platform using C++ and OpenCV library. There is of course the possibility to move the project to other operating system like Windows or Linux because Qt-Creator and OpenCV are multiplatform. Due to the long time involved in the learning process of the system, the phase responsible for this process was written in a way that allows parallelization of operations on multiple processor units. The whole project can operate in four modes. In learning mode, the recognition mode, preview mode and test mode. Of course, the first two modes are standard modes of operation (fatigue analysis).

The algorithm described in this paper has been subjected to many tests. We used public face database The IMM Face Database [26]. It contains 240 face images of different people in different positions. The first half of the images was used to train the algorithm, the second for testing the matching algorithm.

The fatigue detection experiment covered two steps: learning process performed on the public face database and fatigue detection from live camera stream.

Learning process was done for colorful face images as well as grayscale images. The output file from the learning process differs between color and gray scale images. For the colorful images it was approximately 3 times greater in size than in gray scale. Learning time for the colorful input frames took also approximately 3 times more. There is also one important problem in this step. It's a scale of the image during learning process. Algorithm is creating mipmaps of the reference images. It's scaling down reference image always by the factor of two (x1, x2, x4, x8). Time of the learning process (as well as size of the output file) increases with every mipmap scale.

The fatigue detection was tested using live camera stream. It was conducted on the images of authors' faces. We performed four kinds of tests:

- Without any extraordinary lighting conditions (directional point lighting etc).
- With strong left and right directional lighting.
- Colorful recording frames.
- Grayscale recording frames.

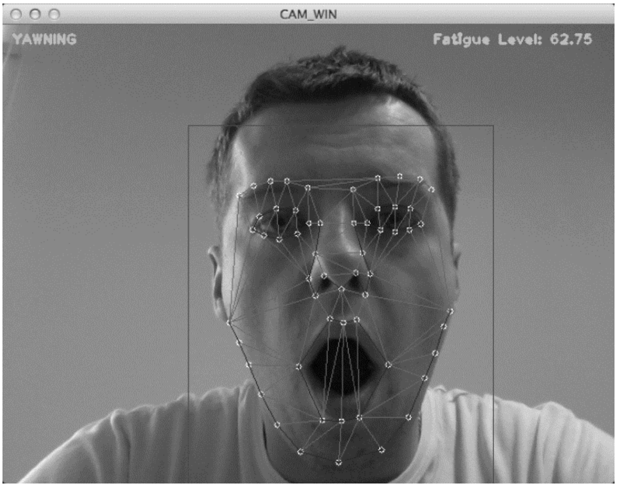

Fig. 1. Image of author's face. The result of the matching algorithms. The net of landmark point is shown. The visible rectangle represents the part of image where face has been found

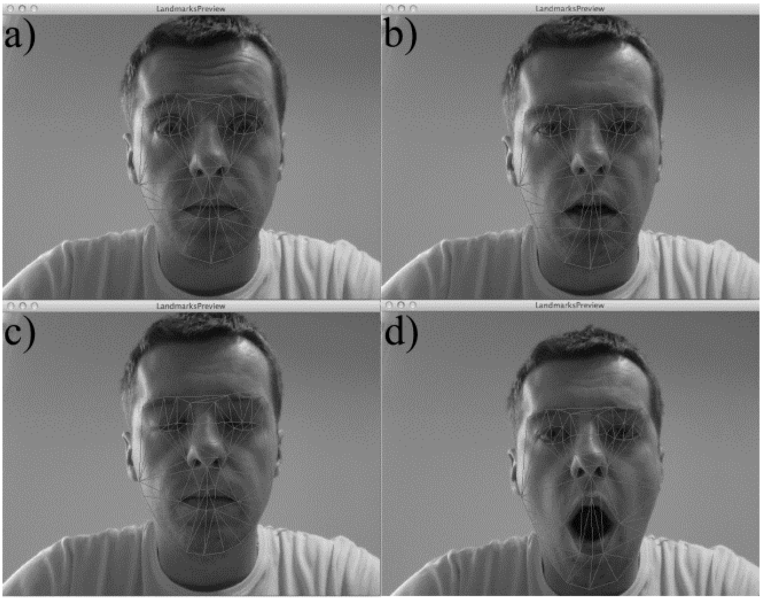

Fig. 2. Image of author's face. The result of the fatigue analysis. a) standard shape of mouth and a little wider opened eyes, decision: no fatigue symptoms, b) standard shape of eyes and a little wider opened mouth, decision: no fatigue symptoms. c) standard shape of mouth and closed eyes, decision: fatigue, d) standard shape of eyes and yawning, decision: fatigue

The matching problem was observed when the image from live camera stream and the strong left and right directional light was used. Landmarks grid not always properly fit into the image frame. In such a case the algorithm could not perform real fatigue test on input frame images. For other test cases 90% match was observed. It confirmed the correctness of the program. In the Figure 1. the result of proper matching is shown. The result of the fatigue analysis for the author's is shown in the Figure 2.

6 Results and Analysis

In the analysis of the proposed algorithm, attention was drawn primarily on learning mode of the system. The more test data is entered, the better description of the changes the shape of the face will be included in the algorithm. However, not only the amount of data is important. The obvious problem is the quality of the images – the better technical quality (sharpness, exposure) and improved image resolution allows for more accurate matching grid. The study also showed that the training set should cover the different lighting options as well as face settings. This allows extending the scope of the analysis of fatigue. Independent problem is the decision of the usage of color images (RGB palette) or black and white (grayscale) in the learning process. Grayscale fatigue detection was performed faster than colorful one and could work on wider range of image data (lower resolutions, small differences in light conditions etc). Good quality color photos provide a better description of the learning process. Research showed, however, that if the test images are much lower quality (or e.g. black and white); they result in errors in the recognition of the shape which leads to poor fit of landmark points. This will result in incorrect operation of fatigue analysis algorithm. It seems that the problem of correlation of image quality between learning and testing modes is an independent serious problem and requires additional study later.

An important problem was the lighting conditions. The strong left / right directional light creates difficult conditions to recognize fatigue effectively. It is caused by matching problem. The developing of the matching algorithm or extended light recognition is needed. This required, however, additional study and future research.

The ICAAM method turned out to be effective for applications in fatigue detection. On the one hand the same algorithm allows detecting shape changes in mouth image as well as in eyes images. On the other hand the tests showed good performance of the iterative algorithm. The best results were observed after 4-5 iterations of the algorithm. After that, no real improvements could be observed in the fitting process. Good quality images make it possible to obtain high quality results in the learning mode. As a result, in the recognition mode, fatigue diagnosis is possible after approx. 5 iterations. In this way the processing of one frame of the video stream takes approx. 0.05s. This gives the ability of analysis up to 20fps (frames per second). This would mean fatigue recognition in real time. Unfortunately, experiments have shown that keeping so fast work of algorithm is very difficult. Temporary change of lighting was enough to extend the matching process more than ten times. In this case, temporary speed of analysis is at level of 2-3fps.

7 Summary

In this paper the use of methods of shape assessment (ICAAM) for fatigue analysis has been proposed. It turned out that the application of ICAAM method was very effective. This gave the opportunity to comprehensive approach to the analysis of the shape of the face. As a result, the same mechanism can detect local changes in the position and shape of the different elements of the face. The study focused on two factors associated with fatigue: on yawning and on closing eyes (Figure 2.). In both cases was carried out the same analysis of changes in the position of the mesh nodes describing the shape of the face. In this way, the addition of another element (e.g. changes in the position of the eyebrows) does not require new algorithm. It is enough to collect proper images of the new behavior and to learn the system. This is a very important advantage of the introduced method.

The proposed solution also has disadvantages. Matching grid using ICAAM creates problems in situations of environmental change (e.g. lighting). Also, the image quality of learning and recognition mode has a very strong impact on the correctness of the analysis. These problems require additional research, and this work will be continued. After a series of experiments, on the basis of the properties of two different symptoms of fatigue, a simple multifactorial formula for assessment of fatigue level has been proposed. Of course, adding another symptom requires an additional modification of the formula.

The results – processing capabilities at up to 20fps offer an opportunity, after optimization and solving the above problems, to implement the proposed algorithm in practice.

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