Affordable Visual Driver Monitoring System for Fatigue and Monotony*

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Abstract – *In this contribution we present a visual driver surveillance system to monitor the driver's head motion as well as the eye blink patterns. Based on these measured features the system is able to detect symptoms of fatigue and monotony. The main advantages of the presented system in contrast to existing ones is the usage of standard equipment to achieve a good cost-performance ratio, fast computation time, the possibility of measurements in darkness and the consideration of monotony. The image analysis is realized in a coarse-to-fine architecture. At first the driver's face is detected which is based on a boosted cascade of Haar wavelets. Then the eyes are searched in the face and occurring eye blinks measured by analyzing the optical flow of the eyes' region. The performance of the system was tested successfully under ideal and natural conditions.*

Keywords: Intelligent Transport, visual driver monitoring, face detection, night vision, image processing.

1 Introduction

Australia's rural roads extend over large distances. The sparsity of traffic, the vehicle's comfort features and ease of manoeuvring, the typically long un-eventful distances covered and the rural road environment are potential factors that contribute to increase driver monotony. While most crash causes are multifactorial, monotony has never been satisfactorily associated with the other factors that contribute to crashes. As the symptoms and causes of monotony are still unidentified the exact number of causalities or social costs due to accidents caused by monotony cannot be estimated. But as per Road Traffic Report of Queensland Government [4], it is assumed that 31% of all accidents are caused by inattention and another 5% by fatigue. Based on this report we suggest that about 20% of all accidents are caused by monotony and fall in the categories of fatigue and inattention.

While there is an impressive amount of literature and projects covering the problem of fatigue and drowsiness (see the publications [1] [2] [9]) the aspect of monotony is neglected so far. Only in the last few years the impact of driving in monotonous environments was investigated and some symptoms of monotony discovered. In a recent laboratory study the different affects of monotonous tasks on different physiological sensors and devices such as EEG, EOG, EKG, GSR and head movement detector are analyzed. The preliminary results concluded that the best combination of sensors to detect monotony consists of GSR (galvanic skin response) and electro-oculograph (EOG - blink rate)[11].

Empowered with such results we present an on-board monotony diagnosis module that monitors the driver's head movements and the length of time between eye blinks because we regard a stare glance as a main symptom for monotony. Furthermore, the presented system can detect the symptoms of fatigue like missing eye blinks or a nodding head. In contrast to other devices mentioned before our system is integrated in the car and does not require any sensors attached to the driver. So the driver's comfort is not reduced by our system. Other advantages of our system are the fast computation time due to a coarse-to-fine strategy and the usage of standard hardware to achieve a good cost-performance ratio.

In the following section the physiological fundamentals of fatigue and monotony will be explained whereas in section 3 the technical details of the vision processes are described. The experimental results will be presented in section 4 before this contribution ends with our conclusions.

2 Physiological Fundamentals

There is an emerging consensus among researchers in the area of road safety that monotony and fatigue represent major road safety hazards and risk factors in private and commercial transportation. But very often the terms fatigue and monotony are used mistakenly as synonyms. From the psychological and medical point of view they are different although both reduce the driver's attention. Therefore we will identify the symptoms and causes of monotony and contrast it with fatigue.

2.1 Fatigue

Fatigue is a widely used term related to a physiological and psychological state. Although it is given as a synonym for drowsiness and tiredness it is often mistakenly associated with sleepiness. Both, fatigue and sleepiness are characterized by a decrease in memory, reaction time, information processing, decision making and vigilance, but one can be fatigued without being sleepy [12]. In general, three different types of fatigue are discriminated: sensory (degradation of sensory perception), muscular and cognitive fatigue [8]. It is important to note that the first two types of fatigue can be measured but every individual reacts differently to fatigue. So a general threshold for fatigue is still undefined.

Other researchers categorize the influence to physiological states into endogenous and exogenous factors [3]. In this context, endogenous factors affect the basic preparation state of the individual when performing a specific task like driving. They are associated with long term fluctuations of alertness that emanate from within the organism. The main endogenous factors include the circadian variations associated with time of day, the fatigue generated with the duration of the task and sleep-related problems. Long hours, late night or mid-afternoon driving periods, as well as sleep deficits, are good examples of widely studied endogenous precursors that are detrimental to driving performance, since they are directly associated with tonic variations of physiological activation [13]. The investigations regarding the relation of fatigue and driving performance are mainly oriented towards the endogenous fluctuation of alertness and sleep research whereas the exogenous factors and the relationship of driver and environment are mostly discounted.

In contrast to endogenous factors, the exogenous ones are related to the specified task and induced by outside influences. An under-demanding monotonous road environment as well as an over-demanding crowded highway have a negative impact on the driving performance.

2.2 Monotony

Monotony is a complex and multidimensional phenomenon which affects drivers' physical, cognitive and affective sensations. The degree of severity and the frequency of such phenomena varies among individuals. Monotony is often associated with three dimensions:

- The nature of a monotonous task. Such a task is often repetitive, predictable and requires low activation of sensory perception. Straight, uneventful and long road infrastructure are well-known factors that contribute to the increase of driver monotony. Radar or lifeguard surveillance are other examples of monotonous tasks.
- The physiological or biochemical state of monotony. This dimension can be detected by sensors such as EEG, skin conductance.
- The psychological dimension of monotony, a subjective symptom of feeling boredom or lack of interest which can generate a range of physiological phenomena.

The causative relationship between a monotonous task and the driver's psychophysiological state is as complex as the relationship between fatigue and endogenous and exogenous factors that cause fatigue. Each individual reacts differently to fatigue or monotony. A more detailed survey of fatigue and monotony is given by Thiffault and Bergeron [13]

The term highway hypnosis is also used generally to describe the effect of monotonous driving conditions [10]. As mentioned before, the symptoms of monotonous state are still unidentified except that an increase of theta and alpha rhythms in EEG are observable. Therefore, we propose to use the visible features of hypnosis like missing eye blink (stare glance) and missing head movements for the recognition of monotony. Additionally, we can analyze the visual information regarding symptoms of fatigue like high eye blink rate or nodding head movements.

3 Visual Monitoring System

The visual driver monitoring system is based on a coarse-to-fine strategy. The images from the camera stream are passing three different processes. The face detection is integrated in the first process, the second one includes the eye extraction from the face area and some image preparation to reduce the amount of data and to speed up the algorithm. In the last process we measure the eye activities or the lack of eye blinks. This is realized by computing the optical flow. Another benefit of this computation is that we get information about the head movement respectively the missing head movement. The main part of the system is the face detection process.

3.1 Face Detection

A lot of different approaches were presented in the last years in the field of face and eye detection. Yang et al. [15] present an overview of face detection methods developed in recent years. The state of the art techniques are appearance based methods which include also a lot of different approaches for object recognition. These methods cover neural networks (NN) and support vector machines (SVM).

The process of face detection used for the system presented in this paper is based on a boosted cascade of *Haar*-like features introduced by Papageorgiou [7] and enhanced by Viola [14] and Lienhart [6]. The fundamentals of *Haar*-like features correspond to *Haar* wavelets. These wavelets are a natural set of functions which encode differences in averaged intensities between different regions. In both papers a machine learning algorithm for rapid object detection based on a boosted cascade of *Haar*-like features is described. To create a classifier for face detection a large amount of pictures showing faces and an even bigger amount of pictures showing no faces is required. The face pictures should comprehend male and female faces as well as different skin color, different head sizes, changing illumination, changing background, people wearing glasses and sunglasses and so on. After the training stage you will get a compact representation of an object class "faces". The used classifier is taken from the Open Source Computer Vision Library (OpenCV) from Intel®[5].

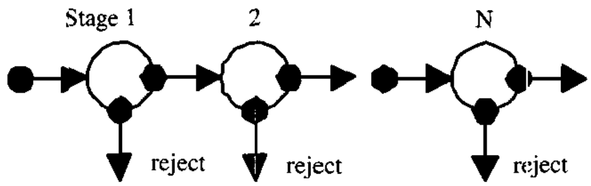

Figure 1: A boosted cascade with N stages

Figure 1 shows a decision tree which displays the boosted cascade of classifiers. At each stage a classifier is trained to detect almost all objects of interest while rejecting a certain fraction of non-object patterns. The input image is divided into smaller images and each of them is analyzed for intensity differences. Only sub windows which exceed the predetermined threshold will be investigated in the next stage, all others will be rejected. The used classifier provides 24 stages and has the advantage that a fast or a more detailed detection process can be performed. After detecting the face in the image all further analysis is placed in the upper region of the found face (ROI). Some results of the used classifier are presented in figure 2 in which the ROI is visualized by a yellow rectangle.

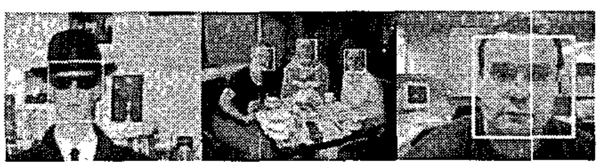

Figure 2: Some results of the face detection process

In the next stage following the face detection the acquired ROI will be searched for the eyes.

3.2 Eye Detection

In this process the eye detection is performed in the extracted ROI by assuming that the eyes are the darkest regions in a face. Therefore, we convert the ROI into a grey level image and after thresholding we get a binary image. In this binary image we search for the major contours with a contour retrieving process. After that we compute the moments and the eccentricity of the segments surrounded by these contours. The first central moments are the candidate points for possible centres of an eye.

The last step in the eye detection process is the eye verification. This is done by evaluating some simple geometric relations between the candidate points as both points should appear in nearly the same row and both points should have a default distance. The darkest points are not exactly the centres of the eyes as you can see in figure 3. Because the eye-socket is not a round object the calculated centre of gravity respectively the central moments of first order are not facing exactly the pupils.

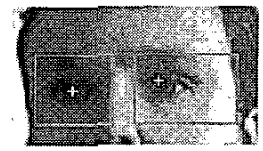

Figure 3: Detection of the eyes

To consider this we cut off larger regions around the eyes to determine the eye blink rate or the lack of eye activities. In the last part we measure the optical flow in each eye region separately and our system is able to raise an alarm if there are no eye blinks during a certain period of time. The investigated eye areas are visualized with the green rectangles in figure 3.

Another big advantage to calculate the optical flow is that we can measure the absence of head movements over a certain period of time as another indication of monotony. A program flow of the optical flow process which is monitoring the eye activities is shown in figure 4. If there are no eye-blinks after a certain period of time an alarm will be triggered.

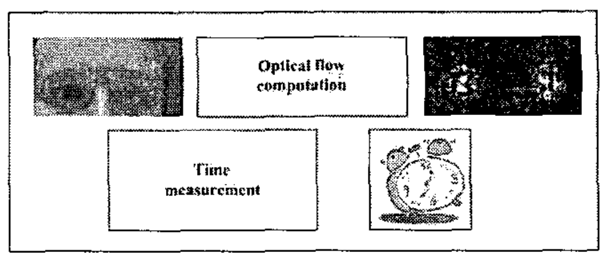

Figure 4: Eye movement detection process

3.3 Night Vision

Most of the actual webcams are very sensitive to infrared wavelengths and so they use an infrared blocking filter to protect the CCD sensor from these wavelengths. For our system we removed the infrared blocking filter from the camera and after that the face detection algorithm is working even in darkness. During dawn or with a small amount of light our system is able to work without an external light source. And to get the algorithm working in complete darkness we use an infrared spotlight with 28 infrared LED's. The spotlight's range is about 5m and the LED wavelength is approximately 870nm. The illumination is invisible for the human eye, so there is no negative impact for the driver. Figure 5 shows an image from a camera stream in complete darkness. Because of the large spotlight range the brightness controller of the webcam has to be closed to get an even darker image. So to implement the system in a car we don't need 28 infrared LED's.

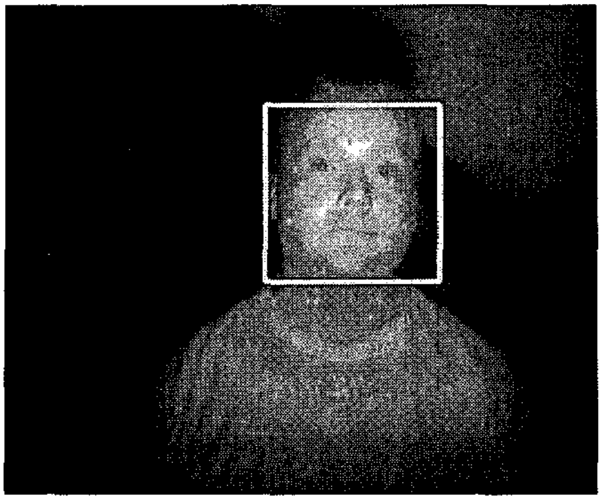

Figure 5: Face detection with infrared illumination

Because night driving especially in Australia is a very monotonous task one of our main goals was to realize a cheap night vision system.

4 Experimental Results

In recent years there have been a lot of projects about visual driver monitoring. The main reasons for driver surveillance are hypovigilance and fatigue. The European Union and some automotive companies like DaimlerChrysler, Siemens and Fiat funded the AWAKE project [1] in 2002. Another driver assistance system (ConnectedDrive [2]) has been introduced in the same year by BMW. And the Australian company Seeing Machines has developed the driver monitoring system faceLAB [9]. These systems are very complex, they use a lot of sensors, very good cameras and they all have the main disadvantage that they are very expensive. Our goal was to implement a very cheap monitoring system without special hardware or complex cameras. On the other hand we want to monitor the driver regarding monotony and as a benefit we can detect the indications of fatigue as well.

4.1 Experimental Setup

In figure 6 you can see one of our webcams used for the experiments in darkness together with the infrared spotlight.

The camera is a modified Philips Vesta Pro with the IR blocking filter removed. For the experiments in the car we have also used an unmodified Philips Vesta Pro and a Kodak DVC 325 webcam. The used PC was a 1.1 MHz Toshiba notebook, so that we have to use the fast face detection algorithm for video streams. In the future we will prepare a faster PC so that we can use a more exact algorithm for face detection. The frame rate and the detection rate should be increased by this. The used image processing library OpenCV from Intel®[5] is open source and to increase the speed of the algorithm we changed the camera interface to Microsoft DirectShow®. The change has also some advantages regarding the installation procedure on the computer.

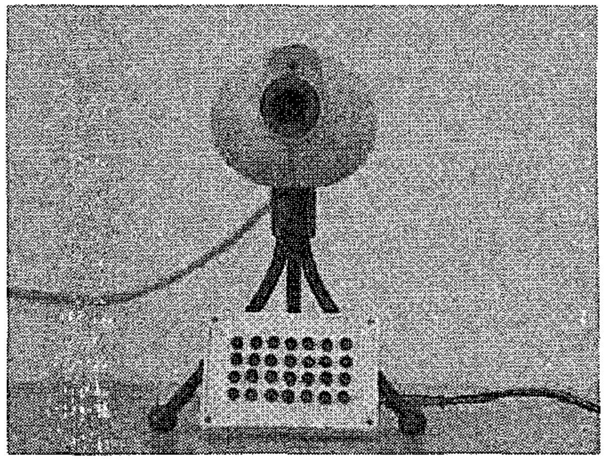

Figure 6: Experimental setup

With this equipment we achieve an excellent cost-performance ratio.

4.2 Results

At first we have tested our system in the laboratory with single images and video streams. Some of the results are shown in figure 2. For these images we have used the exact face detection algorithm, so it is possible to detect all faces in the image. But to detect all faces the algorithm runs about 5 seconds for a single image. But as you can see in figure 2 the results are pretty good. The face of the man with the hat wearing sunglasses is detected without problems. The image processing is implemented such that only one face is detected in the video streams, because we only want to monitor the driver. The used video streams were newscasts and film trailers from the internet. On these video streams we got very good results if the person is looking straight forward into the camera. The achieved frame rate is approximately 5 frames per second.

After that we installed the system in a car to see if the changing illumination, the vibrating environment or the noisy image data has a negative impact on the detection rate. We monitored three different drivers for these experiments. In figure 7 you can see that a different skin color does not have any impact on the detection result as well. During the test run we have discovered two false positive detections in a three minute video stream. False positive detections are detected regions which did not contain a face. These misdetections appeared over less than one second so the error is negligible for our application, because we try to measure the indications of monotony over approximately 10-15 seconds.

There is no negative impact on the frame rate. If we use the exact algorithm in the car we discovered that a second person sitting behind the driver is not detected, because of the darker environment. You can see images from the recorded camera stream in figure 7.

Figure 7: Experimental results in the car

With the optical flow computation we cannot only measure the eye blinks, but we are also able to detect head movements. This is important because the lack of head movements is another possible symptom as well as a glassy stare if the driver falls into a monotonous state.

Most available eye detection systems are not able to monitor the driver in the darkness. Our system shows excellent results in environments with a little amount of light or a complete dark environment. The darkness has no influence on the detection rate. So the night vision part of our system achieves a very good cost-performance ratio as well. The frame rate can be increased by using a more powerful computer.

5 Conclusions

In this publication a visual driver monitoring system is presented. The main advantage is a very good cost-performance ratio compared to other systems. Furthermore a space saving emplacement is possible because all components can easily be installed in a car without any impact on the driver. Our night vision experiments are at the beginning and we achieved auspicious results. We have realized a very good detection rate under real conditions in a car.

The next improvement of the visual driver monitoring system will be the increase of the operating speed. Another idea is to include a separating part which will reduce the amount of processed data.

After improving the speed the system should be installed in buses or trucks to identify the symptoms of monotony and to monitor it's performance.

Another possible improvement could be the training of a classifier directly for eye detection because the main monitoring tasks are located at the eye regions. Our used face detection classifier is trained for faces looking straight forward into the camera so our experimental results can be improved if we use a classifier which is trained for profile images of faces.

Another possible expansion could be the use of a stereo camera system, the OpenCV library from Intel and the DirectShow platform from Microsoft are prepared for the use of two cameras. With this information it is possible to determine the line of sight of the driver.

An extension of our system regarding driver identification is thinkable for theft protection purposes.

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