[ICT03] Development of vehicle driver fatigue monitoring and prevention system

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Introduction

Driver fatigue is a serious hazard in transportation systems. It has been identified as a direct or contributing cause of road accident (Gander et al., 1993). Fatigue can seriously slow reaction time, decrease awareness and impair a driver's judgment. It is concluded that driving while drowsy is similar to driving under the influence of alcohol or drugs (National Sleep Foundation, 2000). In industrialized countries, fatigue has been estimated to be involved in 2% to 23% of all crashes (Knipling & Wang, 1995).

The development of a driver monitoring system capable of producing warning to the driver upon fatigue onset detection can prevent road accidents and thus save lives. Therefore, research on detection of fatigue has sparked much interest in many countries.

However, most existing technologies in fatigue detection are in the prototypic, evaluation or early implementation stages and remain scientifically and practically unproven (Dinges & Mallis, 1998). Complex fatigue detection systems such as the video-based PERCLOS seem potentially very effective, but are not yet commercially available (Horberry et al., 2000). Those complex systems usually require powerful computing devices to perform signal processing. This requirement hinders their practical use.

In this research, two other less computational intensive possibilities of fatigue detection methods are explored and their feasibility is evaluated. The evaluated methods are the steering grip force and the electrooculogram (EOG) signal of the driver.

Instrument setup and data collection procedures

Steering grip force signal acquisition

A pair of resistive force sensors is positioned on the surface of a computer game steering to sense grip force of both the left and right hands. The resistance of the sensors varies according to the force applied on their sensing area. The sensors are connected to a drive circuit to convert the varying resistance into varying voltage. A USB external data acquisition module is used to digitize the signal at sample rate of 50 Hz. In the experiment, two personal computers (PC) are used. One PC is used to record the steering grip force. The other one is used to run driving simulation software. The driving simulation scene is displayed to the experiment subject using a 15 inch cathode ray tube (CRT) monitor. Instrument setup for steering grip force acquisition is displayed in Figure 1.

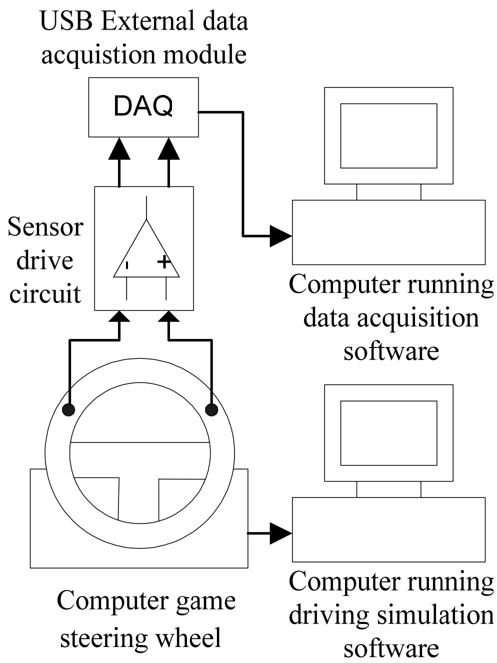

FIGURE 1 Instrument setup for steering grip force acquisition

Condition of fatigue driving is simulated inside the laboratory by having subjects perform driving sessions on driving simulator software with a computer game steering wheel. Steering grip force of a subject is then recorded for off-line analyst and processing.

EOG signal acquisition

EOG is electrical signal generated by polarization of the eye ball and can be measured on skin around the eyes. Its magnitude varies in accordance to the displacement of the eye ball from its resting location.

EOG signal is acquired by placing Ag/AgCl electrophysiology electrodes around the eyes. Two channels of bipolar EOG signal are acquired for analysis, which are the horizontal channel and vertical channel. The horizontal channel EOG reflects horizontal eyeball movements while the vertical channel EOG reflects vertical eyeball movements. Two disposable Ag/AgCl electrodes were placed above and below the right eye to measure vertical EOG while two other such electrodes were placed at the outer canthi to measure horizontal EOG. A silver plated electrode was clipped on the left earlobe, acting as the group point. The placements of electrodes are shown in Figure 2.

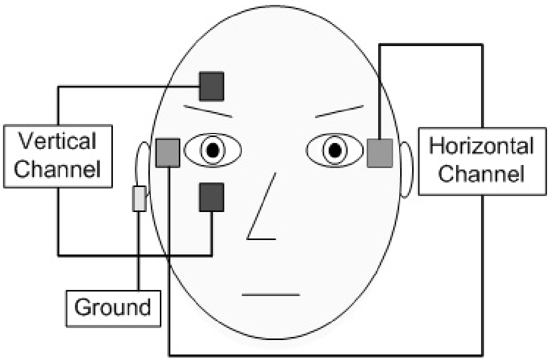

FIGURE 2 Electrode placement positions for EOG measurement

The EOG signals were acquired by using a mobile electrophysiological signal acquisition module with sampling frequency of 256 Hz and resolution of 16 bit. The acquisition module has AC coupled inputs, with frequency response from 0.01 to 30 Hz. The recorded data were stored on a Personal Digital Assistant (PDA) connected to the acquisition module. Upon completion of the recording, the stored data was transferred to a PC for off-line processing. Video recording was performed on the subjects during signal recording to provide reference to the recorded data concerning the subject's alertness.

Data collection sessions involve having subjects sitting on a cushioned chair in an air conditioned room. The experiment procedures were fully explained to the subjects and their written consent were obtained. They were told to relax themselves and take a nap when feeling drowsy. EOG signals were recorded for at least 35 minutes depending on the subject's condition.

Data analysis

Steering grip force

The driver's alertness status is assessed by detecting changes in his steering grip force with change detection algorithm. The steering grip force data is considered as a sequence of independent random variables y_i with a probability density $p_\theta(y)$ depending upon only one scalar parameter, which is the mean of the sequence. Prior to the unknown change time t_o, parameter θ is equal to μ_0 and after the change, it is equal to μ_1. The tool to detect this change in the mean is the log-likelihood ratio, the logarithm of the ratio between probability distribution functions $p_\theta(y_i)$ with θ equal to μ_0 and μ_1 respectively, defined by equation 1 (Basseville et al., 1993).

$$s_i = \ln \frac{p_{\mu 1}(y_i)}{p_{\mu 0}(y_i)} \tag{1}$$

The steering grip force data is assumed to have Gaussian distribution, with mean μ and variance σ^2. The probability density function of the steering grip force is defined by equation 2.

$$p_\mu(y) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(y-\mu)^2}{2\sigma^2}} \tag{2}$$

$p_{\mu 1}(y_i)$ is greater than $p_{\mu 0}(y_i)$ when the local mean of the sequence is equal to μ_1 and smaller than $p_{\mu 0}(y_i)$ when the local mean of the sequence is equal to μ_0. As a result, the sign of the log-likelihood ratio changes from negative to positive when there is a change of the local mean of the sequence y_i from μ_0 to μ_1.

The algorithm used to detect this change is the cumulative sum (CUSUM) algorithm. The cumulative sum S_k of the log likelihood ratio s_i is computed according to equation 3.

$$S_k = \sum_{i=1}^{k} s_i \tag{3}$$

The sign of s_i changes when the mean of the sequence changes, resulting the S_k sequence to reach a minimum point.

EOG

The EOG signal is proportional to the displacement of the eyeball from center fixation point. Thus, the first derivative of the EOG signal is proportional to the velocity of eyeball movement and can be used to distinguish rapid eye movements (REM) which occur during wakeful period from slow eye movements (SEM) that occur during sleep onset. The EOG signal is differentiated to detect REM activities and the duration of REM occurrence is used as an index of alertness.

The first derivative of the EOG signal is approximated by the difference between data points, as characterized by equation 4 where the first derivative of the horizontal channel is represented by ds_x and the horizontal EOG signal by s_x.

$$ds_x(n) = s_x(n) - s_x(n-a), a > 1 \quad (4)$$

The first derivative of any data point is obtained from the difference between that point and another point several samples before it in order to reduce approximation error caused by noise in the signal. Two digital differentiators are implemented according to equation 4 in order to process the horizontal and vertical channels individually.

Information fusion technique is then employed to integrate the horizontal and vertical channels. The EOG signal represents eye movements but is separated into two channels due to limitation of the measurement technique. By integrating both the horizontal channel, complete information of the eye movement can be obtained. Besides that, both channels can complement each other in the process of fatigue detection. The Data In – Data Out (DAI – DAO) fusion which creates new data from several source of raw data as described by Dasarathy (1997) is used to integrate the horizontal channel with the vertical channel.

Since the EOG signal represents eyeball displacement from the central fixation point, the differentiated EOG signal is proportional to the velocity of the eyeball movement. The differentiated horizontal channel signal represents eyeball velocity component in the horizontal direction while the differentiated vertical channel signal represents eyeball velocity component in the vertical direction. The velocity of the eyeball movement, $\boldsymbol{v}$ can be obtained from the vector addition of the horizontal velocity component, $\boldsymbol{ds_x}$ and the vertical velocity component $\boldsymbol{ds_y}$ as indicated by equation 5.

$$\boldsymbol{v} = \boldsymbol{ds_x} + \boldsymbol{ds_y} \quad (5)$$

The magnitude of the eyeball movement velocity is compared with a threshold value in order to locate REM activities. A hard limit function is used to detect REM activities. The function $D_{REM}(i)$ produces 1 to indicate REM activity has occurred when the velocity magnitude is greater than the threshold and otherwise 0 to indicate there is no REM activity as indicated by equation 6.

$$D_{REM}(n) = \begin{cases} 0, v(n) < v_{th} \\ 1, v(n) \geq v_{th} \end{cases} \quad (6)$$

In order to obtain an index of alertness, D_{REM} is framed into N samples using non-overlapping rectangular windows. The sum of D_{REM} values within a frame, N_{REM} is computed. N_{REM} represents the duration of REM activity occurrence within a frame. This value is used as the index of alertness. The computation of N_{REM} of the i-th frame is indicated by equation 7.

$$N_{REM}(i) = \sum_{n=1}^{N} D_{REM}(n) \quad (7)$$

N_{REM} is compared against another threshold value, N_{th} to produce the decision output of this EOG analysis algorithm, indicating whether the experiment subject is awake or sleepy. The binary decision function of this algorithm, $D(i)$ is indicated by equation 8.

$$D(i) = \begin{cases} 0, N_{REM}(i) \geq N_{th} \\ 1, N_{REM}(i) < N_{th} \end{cases} \quad (4.17)$$

When the occurrence of REM activity equals or exceeds the threshold value, the output of the algorithm equals zero, indicating the subject is not in fatigue state. Otherwise, the detection algorithm produces an output of one to indicate that the subject is in fatigue state.

The fatigue detection process through differentiation of EOG signal is summarized in Figure 3.

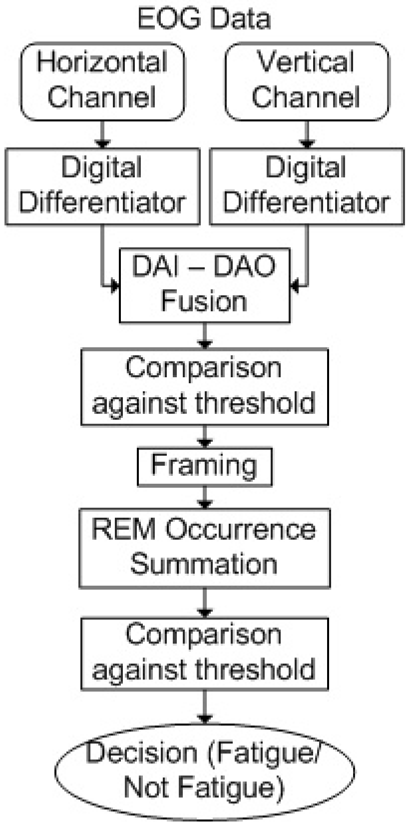

FIGURE 3 Block diagram of the EOG processing algorithm

Results

Steering grip force

The developed change detection algorithm has successfully detected long term changes in the recorded data. The computed log-likelihood ratio exhibits continuous increase after obvious minimum points when long terms changes occur in the steering grip force. Figure 4 shows the output of the CUSUM algorithm which indicates long term change.

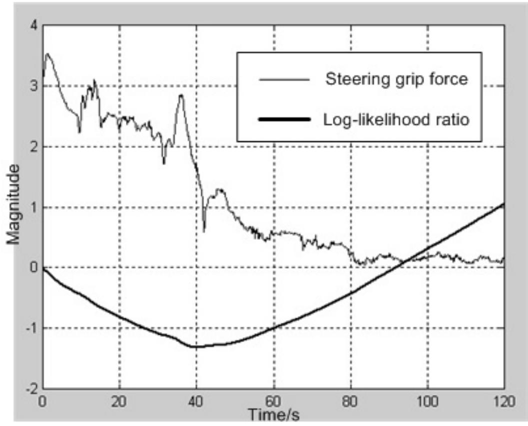

FIGURE 4 The log-likelihood ratio showing minimum point when long term change occurs

However, no conclusive relation can be found between the long term changes in the steering grip force and fatigue. It is not necessarily true that an obvious drop in steering grip force occurs when the subjects are left to fall asleep naturally. Since gripping the steering is a voluntary action, the experiment subject can change the grip force according to situation and personal habit, not necessarily according to level of fatigue.

EOG

32 sets of EOG data with duration of 10 minutes recorded from 10 healthy subjects with ages ranging from 18 to 26 years old were used to test the developed algorithm. The products of different processing stages are shown in Figure 5.

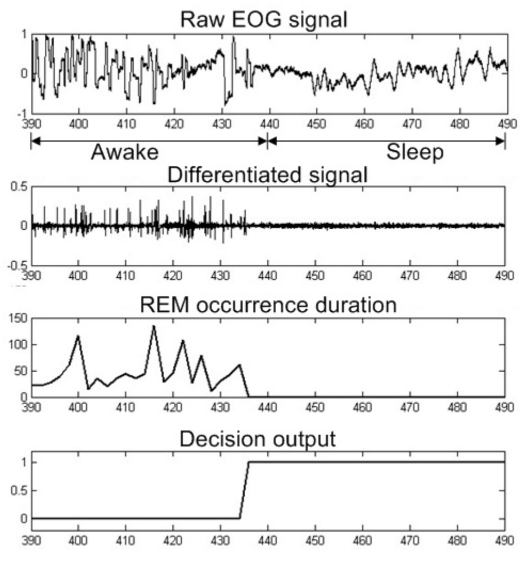

FIGURE 5 Products of different EOG signal processing stages

The performance of the EOG fatigue detection algorithm in terms of detection success rate in different channels is depicted in Table 1.

TABLE 1 Performance of the EOG fatigue detection algorithm in different channels

Channel	Detection Success Rate (%)
Horizontal	87.51
Vertical	86.82
Information Fusion	89.56

From Table 1, it is clear that the EOG signal shows good potential as a fatigue detector. In the individual processing of the horizontal and vertical channels, the horizontal channel produces better result. The combination of the horizontal and vertical channels using information fusion technique produces better result than the processing of either channel individually. Thus, it is evident that information fusion can improve the performance of driver fatigue monitoring.

Implementation of an online prototype

Based on the obtained results, a fatigue monitoring and prevention prototype has been implemented. The prototype continuously monitors the user's alertness level through online processing of his EOG signal. An audible alarm is activated when the user closes his eyes for more than 2 seconds.

The developed prototype comprises of a electrophysiological signal acquisition unit to condition and digitize the EOG signal and a Personal Digital Assistant (PDA) to perform signal processing. The electrophysiological signal acquisition unit also acts as an interface to activate a buzzer alarm through its digital output channels. The software module of the prototype is written by using the Microsoft Embedded Visual C++ 4.0 software development environment and installed on the PDA to process data acquired by the electrophysiological signal acquisition unit. The developed prototype is shown in Figure 6.

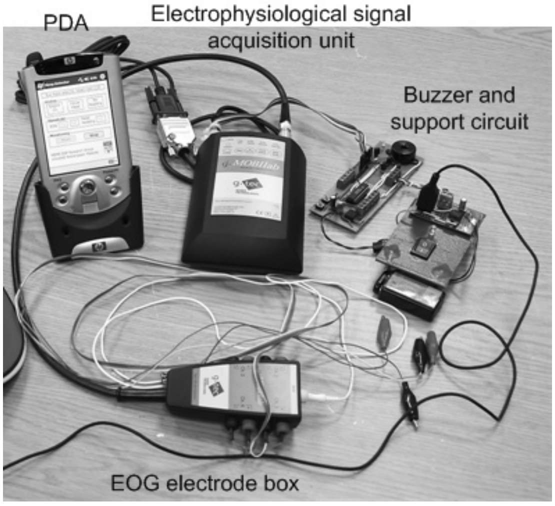

FIGURE 6 The developed online fatigue monitoring and prevention prototype

The developed prototype is in preliminary stage and has only been tested on three subjects comprising of two males aged 26 and 29 years old and one female aged 48 years old. The subjects were asked to open their eyes for around 30 seconds and then close their eyes for another 30 seconds. These actions were repeated a few times to see whether the prototype can detect eye closure. In the conducted preliminary tests, the prototype was able to detect eye closures and produce an audible alarm until the subjects reopened their eyes.

Conclusions

Two alternative methods to detect driver fatigue, namely steering grip force and electrooculogram have been studied in this research. The steering grip force cannot be related to fatigue while the electrooculogram produces encouraging results in detecting signs of fatigue. Information fusion technique has also been employed in this research and has successfully improved the success rate of fatigue detection. Based on the findings of this research, a online fatigue monitoring and prevention prototype has been implemented to evaluate the performance of the developed fatigue detection techniques in real life.

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