Driver Fatigue Detection Based on Saccadic Eye Movements

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Abstract

The correct determination of driver's level of fatigue has been of vital importance for the safety of driving. There are various methods, such as analyzing facial expression, eyelid activity, and head movements to assess the fatigue level of drivers. This paper describes the design and prototype implementation of a driver fatigue level determination system based on detection of saccadic eye movements. Driver's eye movement speed is used to assess driver's fatigue level. The information about eyes is obtained via infrared led camera device. Movements of pupils were recorded in two driving scenarios with different traffic density. In the first scenario, the traffic density was set to low while the second scenario was based on high density and aggressive traffic. Based on the movements of pupils, the data on saccadic eye movement was analyzed to determine fatigue level of the driver. Acceleration, speed, and size of pupils at both traffic scenarios were compared with data mining techniques, such as segmentation adaptive peak, entropy, and data distribution analyses. Significantly different levels of fatigue were found between the tired and vigorous driver for the different types of scenarios.

1. Introduction

Determining the fatigue level of the driver can be vitally important for safe driving. The success of fatigue level estimation is increasing in parallel with developments in the field of signal processing and areas of its application. Owing to the introduction of the electrical vehicle, application areas of fatigue detection systems have been rapidly increasing nowadays. This increase is not only limited to electric vehicles but also includes petrol vehicles and this trend will continue to rise [1].

The determination of driver fatigue level is performed via various methods in parallel with technological developments. Generally, and most commonly, image processing and computer vision techniques, such as eyelid and facial expression analysis, head orientation and eye movement speed are performed to determine the fatigue levels [2]. In addition to that, the diameter of the eyelid is an important and useful parameter to determine fatigue. Unlike these approaches, the characteristic of holding the steering wheel is another useful information for the detection of fatigue level.

The common structure of fatigue detection system (FDS) contains several various components, such as infrared camera, signal processing unit and alarm system [3]. Infrared cameras are frequently chosen instead of traditional cameras due to robustness and clean output images of the eye and its surrounding area [4].

The features that make FDS preferred are robustness and easy integration to the vehicles. In addition to that, the devices of FDS must be user-friendly and feasible; for instance, electroencephalogram-based brain-computer interface (EEG-based BCI) systems have satisfactory results for FDS, however, this kind of devices are not suitable for long-term usage because of the EEG probes or headsets [5].

The image processing or computer vision based features are much more meaningful and easy to use due to difficulties in the implementation of EEG-based BCI systems. For this reason, the eyes' movements or morphological information about the eyes consist of more useful and feasible information; and this is the reason of selecting the eye based features in this work.

The term "saccade" is defined as the quick and short movement of eyes, in the literature [6]. The basic illustration of image processing based FDS is shown in Figure 1.

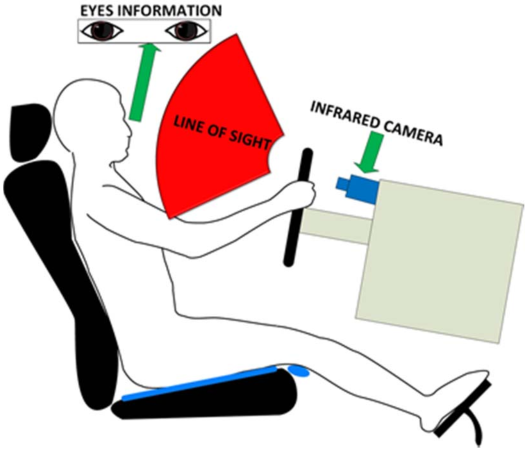


Fig. 1. Driver fatigue detection system

2. Driver Fatigue Detection System

In this section, we explain how we have created our dataset for driver fatigue level analysis. This study focused on a real-time approach to determine the level of fatigue of drivers. Unlike other approaches, a more effective, flexible and easy-to-implement approach has been proposed at this study. It is very important there is not a physical connection between FDS and drivers or users. This kind connection will reduce the difference between the user's behavior in the experimental work process and his / her normal life behavior. In addition to that, the lack of physical connection will also facilitate the integration of such applications as industrial products.

In the first stage, it was targeted to provide that the components of the method are affordable. A low-cost eye tracker system, which is called as Eye Tribe, was found as the result of our literature searches [7]. The specifications of The Eye Tribe tracker are shown in Table 1.

Table 1. The specifications of Eye Tribe

Sampling rate	30Hz and 60Hz mode
Accuracy	0.5° – 1°
Spatial Resolution	0.1° (RMS)
Latency	<20ms at 60Hz
Calibration	9, 12 or 16 points
Operating range	45cm – 75cm
Tracking area	40cm x 30cm at 65cm distance (30Hz)
Screen sizes	Up to 24”
Weight	70g

This experimental study has been tested at two different traffic intensities and these are low traffic density (LTD) and high traffic density (HTD). In addition to that, the fatigue level of the driver is divided into two parts. In the first part, the user is tired at the time of driving. In the second part, the user is driving more vigorously. During the whole process, eye movements of the driver are recorded via eye tracker camera. The sample rate for our test system was about 33 milliseconds. The simulator set used for the experimental study is shown in Figure 2 [8].

Fig. 2. FDS test simulator

The basic anatomy and important areas of the eye are shown in Figure 3 and the information of pupil movement is studied.

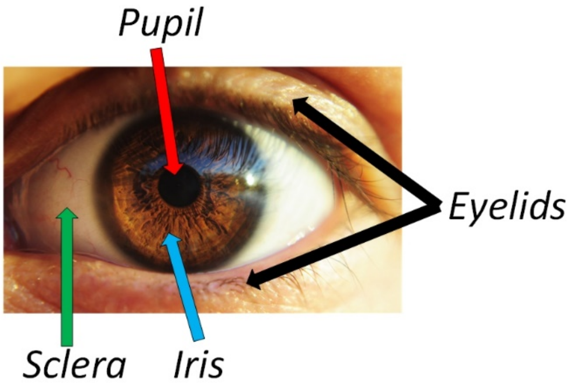


Fig. 3. The basic anatomy of the eye

The parameters obtained by using the camera are shown in Table 2.

Table 2. The Parameters obtained from Eye Tracker

Parameter	***Definition***
PsL	Pupil Size Left
PsR	Pupil Size Right
PcL_x	The x-coordinate of left pupil
PcL_y	The y-coordinate of left pupil
PcR_x	The x-coordinate of right pupil
PcR_y	The y-coordinate of right pupil

These parameters are easily converted to 2D Euclidean spaces as shown Figure 4 and 5. The movements of the left and right pupils are shown in figures below.

The center points of pupils are represented as a small circle for both eyes. Also, the large circles show the actual size of the pupils. Approximately *1800* samples were taken for both of the traffic scenarios and the coordinate information was easily converted to speed and acceleration.

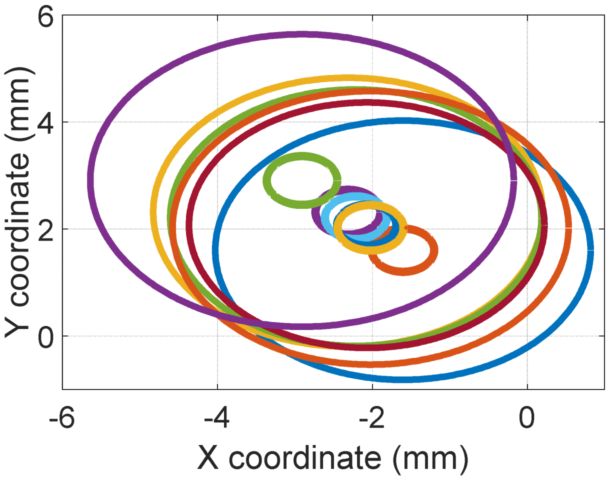


Fig. 4. Output of size and coordinate change for left pupil

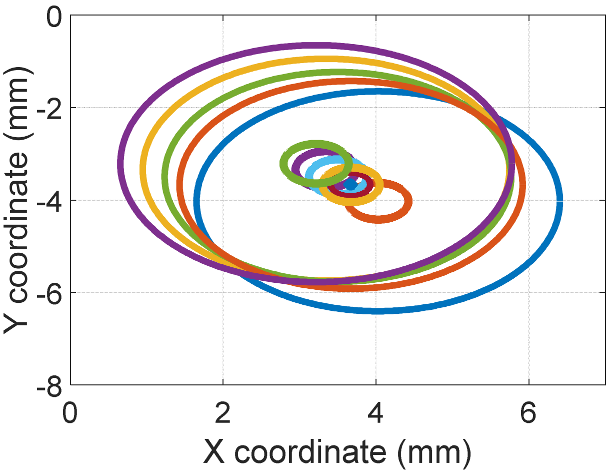


Fig. 5. Output of size and coordinate change for right pupil

The speed and acceleration outputs according to time for the left pupil are shown in Figure 6.

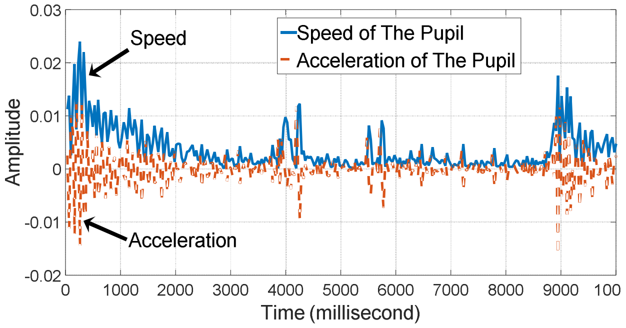


Fig. 6. Speed and acceleration information for left pupil

After obtaining the information, the difference between the eye movements of tired and vigorous drivers has been examined in the light of this information. As the result of our experimental work, the acceleration information of eye pupil is more significant than speed, regarding the information for fatigue level detection. In addition to that, the peak analysis methods were used to distinguish tired and vigorous driver and these methods are applied to accelerate information on this work. The main aim of this study, increase and become more clear and significant the difference between tired and vigorous driver.

3. Adaptive Peak Detection for FDS

In this section, the basic procedure of adaptive peak detection systems for fatigue detection is explained. The number of peaks contains a lot of useful information about the signals. But the fundamental problem in peak analysis is the concept of the peak is highly relative to the user.

The basic approach to peak analysis finds a significant number of different peaks for different situations. From the point of view of our work, we get outputs that will clearly distinguish the difference between a tired and a vigorous driver. In this work, the acceleration of pupil is analyzed for a number of peaks.

The main aim of our work is determined by the significant difference in pupil behavior between tired and vigorous drivers [9]. Users have to select a reasonable threshold value to convert the input signals to the peak signals [10].

One of the basic threshold selecting approaches for peak analysis is shown in Equation 1. The result of peak analysis is shown in Equation 2. The whole process is iterated for low traffic density *(LTD)* and high traffic density *(HTD)*.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \tag{1}$$

$$th_x = \bar{x} + \sigma_x \qquad y_i = \begin{cases} 1 & if\ |x_i| \geq th_x \\ 0 & if\ |x_i| < th_x \end{cases} \tag{2}$$

The result of basic peak analysis for acceleration of left pupil is shown in Figure 7. As shown in Figure 7, there is a significant difference between the total number of peaks for tired and vigorous driver status.

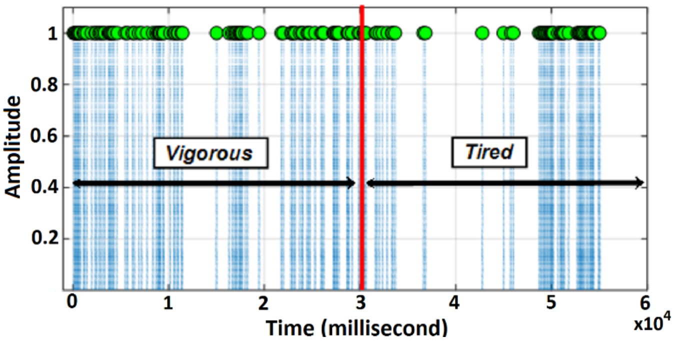


Fig. 7. Result of basic peak analysis for LTD

The equation of peak ratio (p_r) calculation, about driver conditions, is shown in Equation 3. The parameter of *n* is equal to total size of observation array and *i* and *j* are equal to initial observation points for vigorous and tired, respectively.

$$\frac{\sum_{i=1}^{j} P_i}{\sum_{j+1}^{n} P_i} = \frac{Number\ of\ peaks_{vigorous}}{Number\ of\ peaks_{tired}} = p_r \tag{3}$$

The total numbers of peaks about vigorous and tired conditions are *88* and *54*, respectively and $p_r = 1.63$. Unfortunately, this kind of approach is not suitable for real time signal processing application, where users have to know the whole distribution of signals [11].

We need an adaptive and flexible approach to determine the number of peaks and also it should be appropriate for real-time applications. Therefore, *z-score* based adaptive peak detection algorithm is selected for this dataset [12]. This method is suitable for real-time signal processing applications and it has more robust results. The z-score is usually used as a pre-process for data normalization. The equation about z-score is shown in Equation 4.

$$z = \frac{x - \bar{x}}{\sigma_x} \tag{4}$$

This method requires several additional parameters to successfully determine the number of peaks. These are threshold (th_x), lag (l) and influence (i_n). The parameter of influence varies between 0 and 1 and represents the effect ratio of previous observation points on new observation point.

The parameter of lag is equal to the moving screen size for peak analysis, and threshold is defined as a constant for this approach. The generic equations about z-score based adaptive peak determination method are shown in Equations 5, 6 and 7. The z-score based adaptive peak detection algorithm parameters are selected as follows: $th_s = 5$, $l = 5$ and $i_n = 0.5$.

$$\bar{s}_i = \frac{1}{l}\sum_{i}^{i+l} s_i \qquad \sigma_{s_i} = \sqrt{\frac{\sum_{i}^{i+l}(s_i-\bar{s}_i)^2}{l-1}} \tag{5}$$

$$s_i = i_n x_i + (1-i_n)s_{i-1} \qquad z_i = \frac{x_i - \bar{s}_{i-1}}{\sigma_{s_{i-1}}} \tag{6}$$

$$th_s = constant \qquad y_i = \begin{cases} 1 & if\ |z_i| \geq th_s \\ 0 & if\ |z_i| < th_s \end{cases} \tag{7}$$

The result of z-score based adaptive peak detection algorithm is shown in Figure 8.

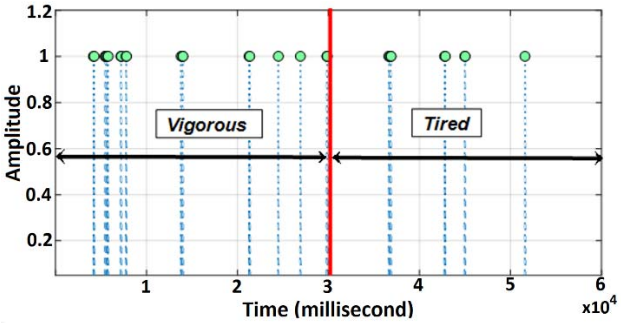
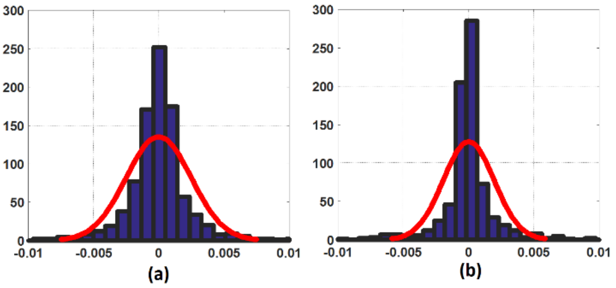


Fig. 8. Result of z-score based peak detection for LTD

As shown in the figure above, this approach has much more robust results. The total numbers of peaks about vigorous and tired driver conditions are 13 and 6, respectively. The ratio of total peak number between vigorous and tired is about *2.166* according to z-score based adaptive peak detection algorithm for LTD.

The histogram with fitted Gaussian distribution curve for LTD is shown in Figure 9. As shown in figure, the fitted Gaussian distribution of vigorous person is much wider than a tired person. This distribution means that vigorous person has more eye movements according to tired person for the same test environment.



(a) (b)

Fig. 9. (a) Vigorous histogram **(b)** Tired histogram

In addition to that, there is a significant difference between driver conditions according to the standard deviation (STD) parameter. These parameters are shown in Table 3 with normalized results.

Table 3. Comparison of STD for LTD

Condition	*STD*	*STD (Normalized)*
Vigorous	*0.002490*	*1.274*
Tired	*0.001954*	*1*

The average time difference between peaks for both driver conditions is shown in Table 4.

Table 4. Average Time Difference Between Peaks for LTD

Condition	*Sample*	*Time(second)*
Vigorous	*77.70*	*2.564*
Tired	*90.80*	*2.996*

All this process is iterated for high-density traffic conditions with same parameters. The z-score based peak analysis results for HTD and movements of left pupil are shown in Figure 10, and the parameters about peaks are obtained as follows: *vigorous driver=20*, *tired driver=11* and p_r *=1.818.*

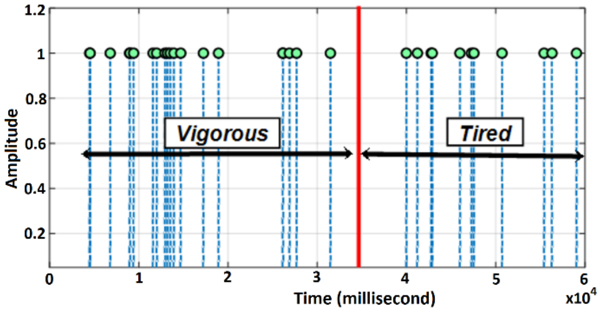


Fig. 10. Result of z-score based peak detection for HTD

The same results were obtained for HTD and the comparison of STD for HTD are shown in Table 5.

Table 5. Comparison of STD for HTD

Condition	*STD*	*STD (Normalized)*
Vigorous	*0.002820*	*1.48*
Tired	*0.001905*	*1*

The average time difference between peaks for both driver conditions is shown in Table 6.

Table 6. Average time difference between peaks for HTD

Condition	*Sample*	*Time(second)*
Vigorous	*43.052*	*1.420*
Tired	*57.802*	*1.907*

Furthermore, the results of z-score based peak detection algorithms are compared with other basic peak detection algorithms, such as average and STD based peak detection algorithms. The ratio of a number of peaks analyses for average and STD based peak detection approaches are *1.507* and *1.187*, respectively. These results were obtained in high-density traffic. As shown in results, the parameter of p_r is useful for fatigue detection systems.

4. Conclusion

In this work, a novel approach is performed to determine driver conditions for different traffic densities (high and low). The coordinates of pupils are obtained via infrared camera and these coordinates are converted to acceleration values of pupils. This information was used to analyze the information of peaks. The z-score based adaptive peak analysis approach is performed to determine the exact conditions of drivers for two different traffic densities. The total numbers of peaks are compared with each other for vigorous and tired driver conditions. There is a significant difference between the peak numbers of the driver's conditions. This difference becomes more apparent in low-density traffic. The ratio of the numbers of peaks between vigorous and tired drivers are *2.166* and *1.818* for low and high traffic density, respectively.

The results of peak analysis approaches are compared with each other, and it was determined that z-score based peak detection algorithm has more successful results when compared to other approaches. As the result of work, it can be stated that saccadic eye movement contains useful information to determine driver conditions. Furthermore, these parameters are easily obtainable with low-cost devices, and the integration of such a system into intelligent vehicles is quite easy.

5. References

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