A Novel Vehicle Safety Model : Vehicle speed Controller under Driver Fatigue

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Summary
Driver fatigue resulting from sleep deprivation or sleep disorders is an important factor in the creasing number of accidents on today's roads. In this paper, we describe a real-time online safety prototype that controls the vehicle speed under driver fatigue. The purpose of such a model is to advance a system to detect fatigue symptoms in drivers and control the speed of vehicle to avoid accidents. The main components of the system consists of a small camera for real-time driver's image acquisition, a nonlinear eye tracking algorithm based on Unscented Kalman Filter for driver fatigue detection, and an adaptive speed controller designed using the theory of sliding mode servo control for providing precise positioning of the throttle valve to control speed of vehicle. This system was tested adequately in a realistic driving environment with subjects of different genders, with/without glasses, day/night driving, commercial/non-commercial drivers, continuous driving time, and under different road conditions. The last experimental results show the validity of the proposed model for vehicle speed controller based on driver fatigue detection.

Key words:
Fatigue detection , Sliding mode servo control, Electronic Throttle Control

1. Introduction

Driver fatigue is one of the important factors that cause traffic accidents, and the ever-increasing number due to a diminished driver's vigilance level has become a problem of serious concern to society. Drivers with a diminished vigilance level suffer from a marked decline in their abilities of perception, recognition, and vehicle control, and therefore pose serious danger to their own life and the lives of other people [1-2]. The National Police Administration in France concludes that 14.9 percents of accident causing human hurt and 20.6 percents of accident causing death is fatigue-related [3]. Statistics show that a leading cause of fatal or injury-causing traffic accidents is due to driver fatigue. In the trucking industry, 57% of fatal truck accidents are due to with a diminished vigilance level. It is the number one cause of heavy truck crashes. Seventy percent of American drivers report driving fatigued. In commercial motor vehicle drivers, 44% took at least one nap during a duty cycle that contained clinically-scorable sleep [4]. The National Highway Traffic Safety Administration (NHTSA) estimates that there are 100 000 crashes that are caused by drowsy drivers and result in more than 1500 fatalities and 71 000 injuries each year in U.S [2]. In China, the number of accident that caused by fatigue is the highest not only in absolute figure but also in proportion. With the ever-growing traffic conditions, this problem will further increase. Therefore, how to avoid fatigue driving efficiently can help prevent many accidents, consequently save money and reduce personal suffering. For this reason, developing driver fatigue detection systems and related intelligent safety applications are very important to vehicular systems in the future.

In the past ten years, many countries all over the world have begun to pay attention to the driver safety problem and to investigate the driver's mental states relating to driving safety. And some driver fatigue methods have been proposed which can detect whether the driver is tired, such as drowsy or inattention, for generating some warning alarms to alert the driver [1-8]. All of these efforts [1-8] have been reported in the literature for developing an active safety system for reducing the number of automobile accidents due to driver fatigue.

Despite the success of the existing approaches/systems for extracting characteristics of a driver using computer vision technologies, current efforts in this area, it is a challenging issue due to a variety of factors. The first reason is the variety of eyes moving fast, external illuminations interference and realistic lighting conditions. So non-intrusive eye tracking is a very difficult work in driving environments. At the same time, it's very difficult to model the driver's eye movement dynamics because of the eye motion being the high nonlinearity. The third question is the safety ramifications of the proposed systems which turn off the engine and stop air into the

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combustion section, or brake sharply to stop vehicle. Many systems adopt turning off the engine or braking sharply to stop vehicle when the fatigue detected reaches a predefined level, but the safety ramifications are not answered by these approaches. I think the third reason must be taken into account for these systems. It seems that doing that on the road would probably kill the driver and several other people as well.

In this paper, we propose a new advanced safety model that controls the vehicle speed based on driver fatigue detection. Firstly↵ we propose a novel real-time robust method for fatigue detection based on the Unscented Kalman Filter[5,6]. Secondly, if driver fatigue is confirmed, an adaptive speed controller is proposed using the theory of sliding mode servo control for providing precise positioning of the throttle valve to control speed of vehicle to prevent accident. Fig.1 gives an overview of our safety system. The last experimental results show the validity of the proposed model for vehicle speed controller under driver fatigue.

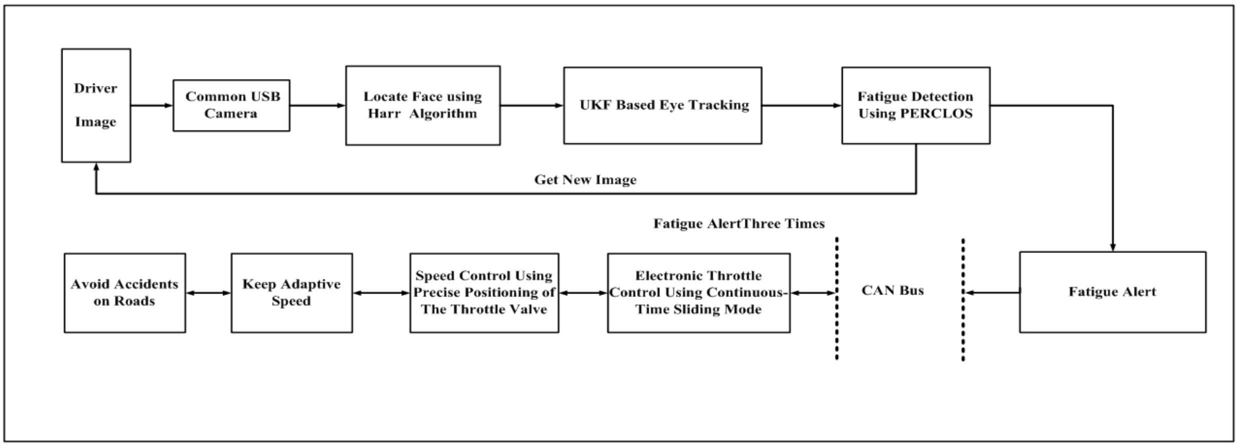

Fig.1 Flowchart of the proposed safety model

The organization of the paper is as follows. Vehicle speed controller under driver fatigue detection is designed in section2. Experimental results and discussion are presented in section 3. Finally conclusion is in section 4.

2. Vehicle Speed Controller under Driver Fatigue

The flowchart of fatigue detection in Fig.1 gives an outline. Firstly, we use Haar algorithm to locate the face and projection technique for eye location. And Haar algorithm has good robustness in terms of head motions, variable lighting conditions, the change of hair and having glasses, etc. Secondly, we propose a new real time eye tracking method based on Unscented Kalman Filter. Thirdly, driver fatigue can be detected using PERCLO. For detailed eye tracking method based on Unscented Kalman Filter, refer to [5,6].

After driver is drowsy, some proposed systems which turn off the engine for avoiding traffic accidents [6,9,10,11]. But few authors are concerned the safety ramifications of their proposed systems. The driving system of front wheel drive consists of an engine, a clutch system, a manual transmission, drive shafts, final drive, front wheels and back wheels. The torque route-line of driving vehicle is engine——clutch system——gear shaft——manual transmission——middle drive shaft——front drive shaft——final drive——front wheels. When driver operates the accelerator pedal, more air enters into the combustion section and the torque is obtained. This torque makes vehicle wheels go forward under the demand of driver. If the systems which are proposed in [6,9,10,11] turn off the engine while driving on the road at high speed, it seems that doing that would probably kill the driver and several other people as well. At this time, the engine stop working, and the inertia makes vehicle slip at high speed. So the dynamic transmission route-line is wheels——final drive——front drive shaft——middle drive shaft——manual transmission——clutch system——engine. From above analysis, if clutch system does not disengage, the inertia force of vehicle maybe drag the engine as reverse way. This inertia force will make engine Disabled and transmission gear tooth crack.

From above analysis, turning off engine or braking sharply to awaken the sleeping driver is very dangerous. On the highway, it seems that doing that will increase the probability of serious injury or fatal accidents. We proposed that sound the auditory alarm to awaken sleeping driver firstly. If fatigue is going on, the adaptive speed control system is an optional system that could provide speed control for avoiding traffic accidents. If the adaptive speed control system is start-up, the throttle valve is controlled by Electronic Control Unit (ECU) instead of sleeping driver. At this time, when driver operates the accelerator pedal, the throttle opening angle can’t increase, and no more air enters into the combustion section. The vehicle keeps current speed, and controls speed under safety zone. The strategy to adaptive speed control of the vehicle is to slow down the acceleration at 1.389 m/s^2 to safety zone using throttle valve control. If speed slows down to 20km/h, the throttle valve keeps this angle and avoids no air enters into the combustion section to turn off engine. In our proposed vehicle safety model, if driver is awakened by alert signal, the adaptive speed control is not used, and vice versa.

From above safety ramifications analysis, the adaptive speed control is a suitable strategy which is used to avoid traffic accidents. It is intended to keep adaptive speed to decrease the accidents after driver fatigue is confirmed. In this section, we will design a speed controller for the throttle valve that is used in combustion engines for the purpose of controlling the speed of the vehicle. This vehicle speed controller can keep adaptive speed after driver is fatigue.

2.1 Adaptive Vehicle Speed Control: Principles of Operation and Implementation

In traditional systems, the throttle position is actuated by a mechanical link with the accelerator pedal in Fig.2, only operated by the driver. The amount of air flow into the engine has been adjusted by the throttle which is connected to the accelerator mechanically. Therefore, this method can’t deal with the adaptive speed control and other intelligent strategy. Recently, there appeared a trend in the automotive industry of using an electronically controlled throttle valve in order to provide precise positioning of the throttle to control vehicle speed [12]. The desired reference position which is generated by an external computing module according to the desired speed of motion and current engine torque should be tracked by the valve.

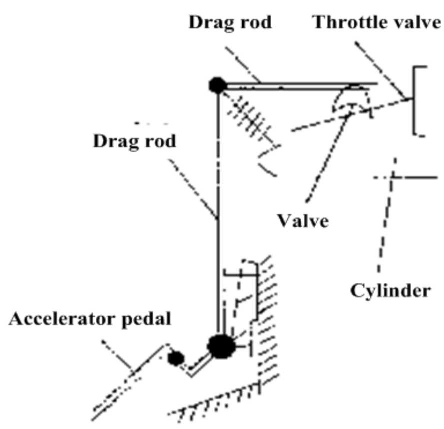

Fig.2 Conventional throttle system

Electronic throttle is increasingly being built in automotive engine in order to improve vehicle emissions, fuel economy, driveability and other intelligent strategy. As shown in Figure 3, the electronic throttle valve body consists of a DC servo motor, a motor pinion gear, an intermediate gear, a sector gear, a throttle valve, and two nonlinear springs. The electronic throttle is a DC servo drive which needs to provide precise positioning of the throttle valve. The electronic throttle control means computer controlled throttle valve instead of a mechanical wire. A driver steps on an accelerator pedal. The pedal angle is measured by a sensor and transported through an electric wire or an optical fiber to ECU, which is a controller of the throttle. The ECU makes a control input based on the pedal angle to feed a DC servo motor, which moves a throttle valve. Gear box provide gear ratio to control the action of spring. The throttle valve is constrained by a dual return spring, which reams the valve into its initial position (so-called limp-home position) in the case of power supply failure.

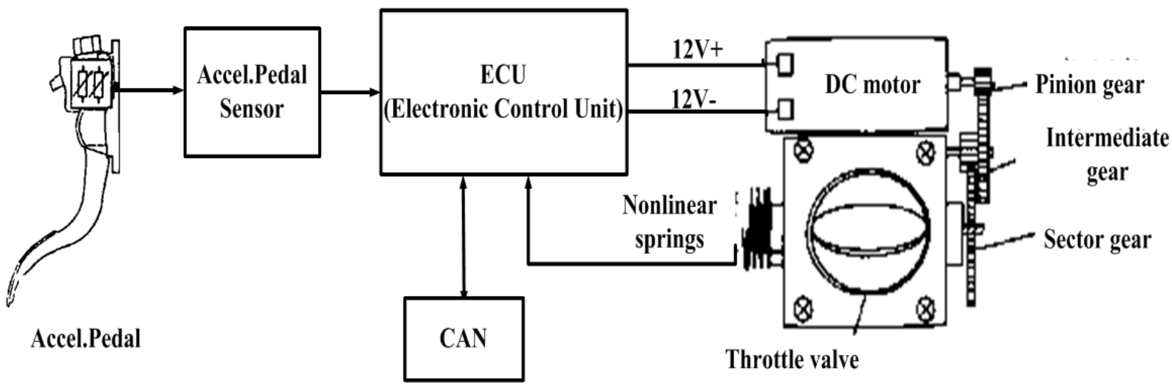

Fig.3 The general view of electronic throttle valve system

The theory of sliding mode control has been developed for a long time and applied to the control of various systems [13]. There are many excellent properties in the sliding mode, such as robustness against large variations in the system parameters and disturbances. The motivation for the use of sliding mode controller stems from the fact that the throttle valve in our developing electronic throttle control system (ETC) is supported by two springs which can be modeled as a nonlinear discontinuous spring. This situation, however, satisfies the matching condition in the sliding mode control theory, namely the robustness is guaranteed is guaranteed during sliding mode. Furthermore, the rise time is required to be as small as possible without overshoot.

In this paper, we describe a sliding mode servo controller to provide precise position of the throttle to control vehicle speed. As shown in Fig.4, the characteristics of these springs can be modeled as discontinuous spring in the whole operation region. Thus the block diagram of the electronic throttle control (ETC) can be shown in Fig.5. For simplicity of the description, we use the motor angle instead of the valve angle as the control variable and consider the default angle as the origin. Thus the mechanical model is written as

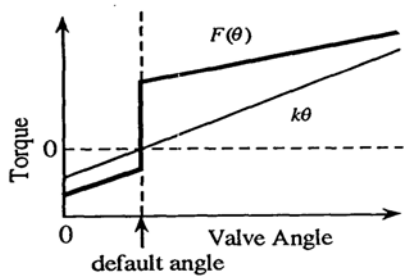

Fig.4 Characteristics of the spring

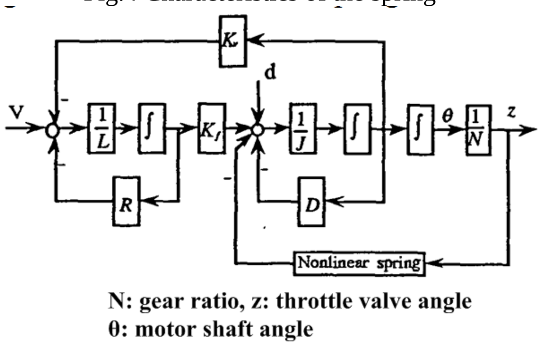

Fig.5 Block diagram of ETC

$$J\frac{d^2\theta}{dt^2}+D\frac{d\theta}{dt}+F(\theta)+d=K_f i \tag{1}$$

$$L\frac{di}{dt}+Ri+K_v\frac{d\theta}{dt}=u \tag{2}$$

where

θ : motor shaft angle J : inertia D : friction constant $F(\theta)$: spring torque d :disturbance K_f :torque constant i :current L :coil inductance R :resistance K_v :emf constant u :input voltage

Denoting the discontinuous spring as a nominal linear spring and disturbance

$$F(\theta)=k\theta+f_D(\theta) \tag{3}$$

and eliminating the coil inductance, the following linear model of reduced order is obtained.

$$JR\frac{d^2\theta}{dt^2}+(DR+K_vF_f)\frac{d\theta}{dt}+Rk\theta+Rf_D(\theta)$$
$$=K_f(u-d_1) \tag{4}$$

We denote the disturbance due to the spring apart from other disturbances, because we can estimate $f_D(\theta)$ in advance and use it for nonlinear feedback control to reduce the chattering.

Using the state vector

$$x=\begin{bmatrix}\theta-r & \int(\theta-r)dt & \dot{\theta}\end{bmatrix} \tag{5}$$

the state space model of ETC can be written as

$$\dot{x}=Ax+bu+g_1\dot{r}+g_2r+h_1d_1+h_2f_D(x_1) \tag{6}$$

Denoting the switching function as

$$\sigma=\alpha x=\begin{bmatrix}\alpha_1 & \alpha_2 & 1\end{bmatrix}x \tag{7}$$

the control input can be expressed as follows:

$$u=u_{eq}+u_{nl}+u_l+u_f \tag{8}$$

Where

$$u_{eq}=-(\alpha b)^{-1}(\alpha Ax+\alpha g_1\dot{r}+\alpha g_2 r)$$
$$u_{nl}=\gamma(\alpha b)^{-1}\operatorname{sgn}(\sigma)$$
$$u_l=\lambda(\alpha b)^{-1}\sigma$$
$$u_f=\frac{R}{K_f}\hat{f}_D(x_1) \tag{9}$$

u_{eq} is the equivalent control input, u_l is the proportional rate reaching input , and u_f is used for compensation of the modeling m r of the spring. It should be noticed that the sliding mode can occur with the only relay input u_{nl} . However, in this case its gain should be larger and the chattering will appear more heavily. It is the reason why we use other inputs as well as the relay input. During the sliding mode, the transfer function from the reference angle to the actual valve angle is given by

$$G\ (s)=\frac{\alpha_1 s+\alpha_2}{s_2+\alpha_1 s+\alpha_2} \tag{10}$$

The last experimental results show the validity of our proposed sliding mode servo controller of ETC will implement the adaptive speed control strategy, which the vehicle is low down the acceleration at 1.389 m/s^2 to safety zone using throttle valve control. If speed slows down to 20km/h, the throttle valve keeps this angle and avoids no air enters into the combustion section to turn off engine. In general, our proposed sliding mode servo controller of ETC can provide precise position of the throttle to adaptive speed control.

2.2 Electronic Throttle Control under Driver Fatigue

As the application of driver fatigue detection, we design an electronic throttle control system model to avoid fatigue driving as proposed above. The architecture of electronic throttle based on driver fatigue detection is shown in Fig.6. It consists of MMI module, inner control loop module, ECU, alert & display module, vehicle on-board sensors module, ETC system, reset module and other sensors. The MMI (man-machine interface unit) module can communicate with driver fatigue detection system. And the inner loop module is the most important parts which can control the throttle valve of vehicle using sliding mode theory. If the driver drowsiness condition has been detected, an auditory stimulus informing alarm would be activated unless the manually depresses the reset button. The advisory stimulus would consist of an audible tone followed by a voice message, and it is therefore set at a substantially higher sound level than advisory messages and tones.

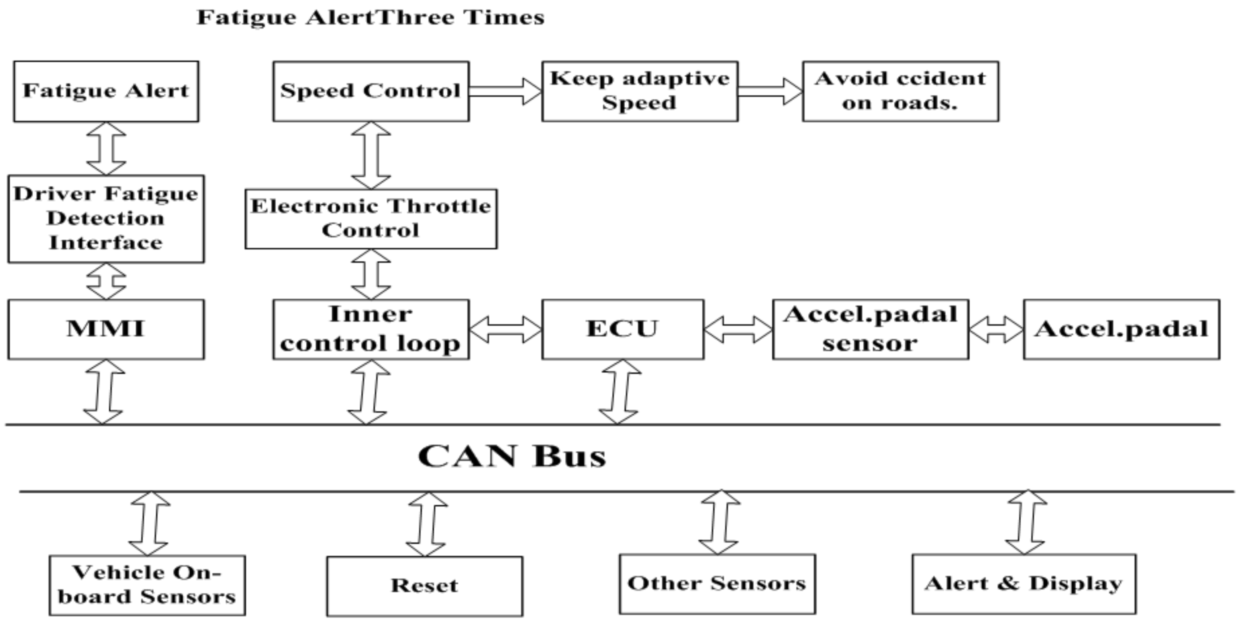

Fig.6 Architecture of electronic throttle control based on driver fatigue detection

If the advisory stimulus alarm can't reawaken the sleeping driver after alerting three times, the electronic throttle control based on driver fatigue detection would start up to realize adaptive speed control to avoid accident. The ECU is a very important electronic unit in the vehicle, and is a controller of the throttle in our proposed system. The pedal angle is measured by a sensor and transported through an electric wire or an optical fiber to ECU. The ECU makes a control input based on the pedal angle to feed a motor, which moves a throttle valve. The vehicle on board sensors, and other sensors can be classified as general-purpose modules since they are typically shared among several applications.

3. Experimental Results and Discussion

This part of the research is to experimentally and scientifically demonstrate the validity of propose safety model. In order to obtain valuable data, the proposed system was tested adequately in a realistic driving environment. As shown in Table. 1, twenty (20) properly qualified drivers between the ages of 25 and 50 served as subjects in this study. Drivers had to have at least one year of experience driving, and they had to be medically qualified and free from controlled substances and alcohol.

Drivers		Total
Male	15	20
Female	5	
With glasses	9	20
Without glasses	11	
Commercial drivers	10	20
Non-commercial drivers	10	

Table.1 Twenty drivers served in this study

Each participating vehicle is outfitted with on-board monitoring camera and a data acquisition computer. The proposed method is tested on a Pentium III 1.7G CPU with 128MB RAM in the test vehicles. And the experimental vehicles use ViewQuest VQ680 video cameras to capture driver's images. Driver fatigue detection based on the proposed method can reach 10 frames per second for fatigue tracking. The format of input video is 352×288 pixels. The experimental vehicles are in Table. 2.

Vehicle	Quantity	Vehicle configuration
Non-commercial vehicle	2	SUZUKI CH7140
	3	Volkswagen 1.6
	3	Honda CRV SUV
	1	Nissan SUV
	1	Toyota corollar
Commercial vehicle	4	Volkswagen Santana
	3	Volkswagen
	1	Truck
	1	Bus
Total	20	

Table.2 Twenty experimental vehicles in this study

In order to show the validity of the proposed model, this system was tested adequately in a realistic driving environment with 6 subjects of different genders, with/without glasses, day/night driving, commercial/non-commercial drivers, continuous driving time, and under different road conditions.

The experimental results on the test videos are shown as follows:

1) Result of fatigue detection

PERCLOS was found to be the best potential measure of fatigue drawn from a range of ocular variables studied above researches. In this paper, the accuracy was scored by using two levels of fatigue thresholds [14] as shown in Table 3. Fig. 7 shows the PERCLOS estimates for the 20 drivers.

Questionable	0.075≤PERCLOS < 0.15
Drowsy(Fatigue)	PERCLOS≥0.15

Table.3 PERCLOS thresholds

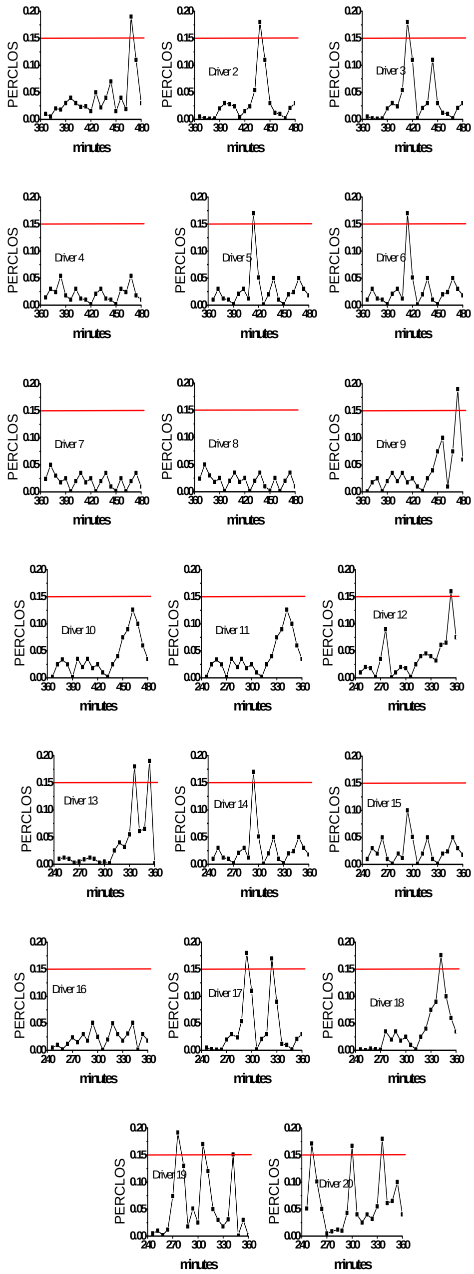

Fig 7 PERCLOS estimates for 6-min intervals for driver 1-driver 20.

The study developed a massive database which covers more than 6,000 miles of driving. It includes some 140 hours of video data, 5,040,000 frames of driving record, and 40 hours computing results of PERCLOS. Fig. 7 shows the results of fatigue detection on the twenty videos. The last 2 hours data are into 6-min intervals to compute PERCLOS estimates. From Fig.7, fatigue is obvious after longtime driving on the roads. The fatigue probability of nighttime driving is higher than daytime driving. In driver 19 and driver 20, fatigue appears three times (exceeding PERCLOS Drowsy threshold three times).

2) Results of electronic throttle control and adaptive speed control

In order to test the performance of adaptive speed control system, it was examined by various simulations in these test videos which drivers were drowsy. The performances of proposed electronic control and adaptive speed control have been shown in Fig.8, Fig.9 and Fig.10.

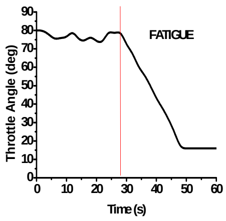

Fig 8 Simulation result of electronic throttle control based on fatigue detection

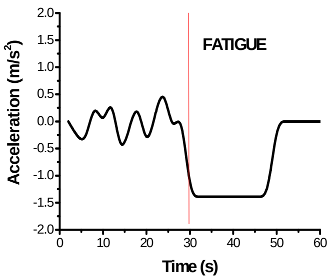

Fig 9 Simulation result of acceleration

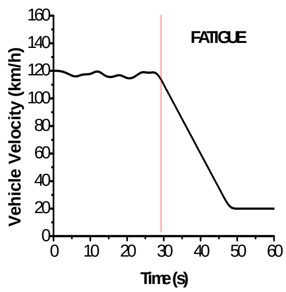

Fig 10 Result of adaptive speed control after fatigue

4. Conclusions

Through research presented in this paper, we propose a new advanced safety model that controls the vehicle speed under driver fatigue. Firstly↵ we propose a novel real-time robust method for fatigue detection based on the Unscented Kalman Filter[5,6]. Secondly, if driver fatigue is confirmed, an adaptive speed controller is proposed using the theory of sliding mode servo control for providing precise positioning of the throttle valve to control speed of vehicle to prevent accident. This model was tested adequately in a realistic driving environment with subjects of different genders, with/without glasses, day/night driving, commercial/non-commercial drivers, continuous driving time, and under different road conditions. The experimental results show the validity of the proposed model for vehicle speed controller under driver fatigue.

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