Towards Early Status Warning for Driver's Fatigue Based on Cognitive Behavior Models*

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Abstract. Based on ACT-R (Adaptive Control of Thought-Rational) cognitive architecture this paper implements researches on a status warning system for driver’s fatigue, its goal is applying vehicle performance output and cognitive science to build driver behavior model, using non-invasive detection method that retrospect driver behavior based on model to monitor driving status, and to reach the aims of driver status monitor and early warning. First, based on the different detection methods' analysis of driving fatigue, the predominance of cognitive science, and the inherent relationship between driver behavior and cognitive science, the advantages of applying cognitive theory to researches on driver fatigue are clarified. Then, based on the analysis of the factors contribute to fatigue related accidents and observations of drowsy driving cases, the viewpoint that the fatigue driving is consist of three stage and corresponding to three status is proposed; accordingly, the declarative and procedure knowledge for ACT-R architecture is extracted, and driver fatigue behavioral model is implemented on the ACT-R software platform. Finally, the simulation methods are applied to verify the model's validity and a framework of driver status monitor and early warning system that contains the cognitive fatigue driver behavior models is put forward. The research results indicate that the fatigue driver behavior model has a strong advantage in the researches of driver status monitor and early warning.

Keywords: Cognitive driver behavior, driver status warning, ACT-R.

1 Introduction

Driver fatigue is serious potential threats of traffic crash for its high rate accidents and serious consequences. The experts pointed out that the risk of driver fatigue is as dangerous as drunk driving. An 18-hour without sleep is equivalent to half drunk, and a 24-hour without sleep is equivalent to drunk. A 1991 report by the National

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Highway Traffic Safety Administration indicates that driver drowsiness as one of the leading causes of single and multiple car accidents [1].

1.1 Research on Fatigue Driving

Various methods have been taken to detect driving fatigue and give early warning in the early days and some mechanical devices are used in the mid-1960s and early 1970s. Nowadays, driver fatigue research focus on developing algorithms for the detection of drowsiness. During Driving fatigue studies, the researchers used different techniques to solve the problem of driver fatigue detection. Due lots of advantages especially the characteristics of non-intrusive, the detection of driver fatigue by using vehicle performance's output is more acceptable to the driver [2].

1.2 Research on Cognitive Driver Behavior Modeling and ACT-R

Driver cognitive behavior modeling method gradually developed into a field of intelligent transportation system and become one of the hottest research topics recently. Truls VAA (2001) noted that cognition and emotion are a good tool for prediction, avoidance and evaluation of dangerous during driving task. After that, Salvucci DD (2002), Daiel Krajzewicz (2002) and Delphine Delorme (2001) etc. launched research work on the driver behavior in cognitive architecture. Liu (2006) is also conducted driving behavior modeling studies on the basis of cognitive tools CogTool[4].

ACT-R is one of the most typical and widely used cognitive architecture. It aims at using software to simulate a full range of cognitive tasks. Its constructs reflect assumptions about human cognition. These assumptions are based on numerous facts derived from psychology experiments. Research on ACT-R cognitive architecture is related closely to the latest achievements of neurobiology.

2 Driver Fatigue Cognitive Model in ACT-R

2.1 Modeling Driver Cognitive Behavior Using ACT-R

Driving task is the whole process which is consist of several continuous small pieces of basic task. Driver cognitive behavior is the compound of driver's perception, cognition, manipulation, and implementation for certain anticipating task [5]. Michon (1985) groups three classes of driving task, monitor, decision-making and control. the ACT-R cognitive architecture is a production executive system, driver cognitive behavior model in ACT-R is a program running in the ACT-R platform. The model handle external input and output internal information, and execute productions such as monitor, decision-making and control which represent knowledge of driving task. The model is the realization of ACT-R production system for declarative knowledge and procedural knowledge as well as driver's operation and purpose. Sequential execution circularly for monitor, decision-making and control driving tasks in ACT-R cognitive processor forms closely connected cognitive task's stream[6]. The most important thing for ACT-R model is to extract declarative knowledge, procedural knowledge and model's parameter.

2.2 Driver Behavior Characteristics of Fatigue Related Accidents

To obtain fatigue driving knowledge, related research are investigated here firstly to find characteristic of fatigue driving. There are many researchers who focused on steering-wheel manipulation behavior to detect fatigue [7], such as Horne and Reyner (1995) propose identification criterion for fatigue-related accidents which vehicle go off the road, there is no brake evidence, there is no mechanical failure, the weather is good, and exclude over speed, and Hulbert's research (1972) found that comparing with normal drivers sleep-deprived drivers conduct low-frequency steering-wheel back (steering angle exceeds zero degree) operation. The related researches indicate that when fatigue driving the driver's steering-wheel manipulation ability reduced, even there is no steering-wheel operation as it is necessary. Lower or loss of steering-wheel control ability is main characteristics of driver fatigue driving behavior [8].

2.3 Characteristic of Fatigue Driving Behavior

To descript easily, the procedure that from driver's awareness to fatigue and finally cause accident are divided three stages and defined three status accordingly, i.e. tiredness, insensitiveness, and drowsiness. Tiredness, the in this stage the driver try to take measures (such as drinking cola, coffee and hard rubbing eyes, hard opening eyes wide, etc.) to make himself sober, the driver maintains sober, and the driver have necessary driving ability for perception, cognition, decision-making and control (PCDC). Secondly insensitiveness, in this stage driver is consciousness, may be awakened by the sudden events, and lack normal driving ability for PCDC; As to the steering-wheel operation, the characteristic is low-frequency small-angle steering-wheel operation and sudden steering-wheel operation. And drowsiness, in this stage the driver lose normal driving capacity for PDDC, run into obstacles, isolation belt or off the lane when running in curve road, and result in fatigue driving accident.

Research shows that the fatigue driving has follows characteristic in time, road shape/type, vehicle speed, and driver's steering-wheel operation. For time characteristics, most fatigue driving occur in the time period between 02:00 to 07:00 and 14:00 to 16:00, for road and vehicle speed, the fatigue driving occur in good road surface and highway, and for driver and behavior, three status of tiredness, insensitiveness, and drowsiness appears and corresponding steering-wheel operation is implemented.

3 Driver Fatigue Behavior Modeling

3.1 ACT-R Driver Fatigue Model

The declarative knowledge, the procedural knowledge, and model’s parameters can be obtained from the characteristic of fatigue related accidents, fatigue driving behavior and the driving environmental conditions. The model is primarily composed of two main parts, the manual controlling part and model part. The manual controlling part implement user's manual controlling function, and the model part includes the chunk type's definition, declarative knowledge, model's first goal and all the procedural knowledge.

3.2 The Principle for Fatigue Status's Judgment

Sometimes the model can judge driving status by several declarative knowledge and procedural knowledge, however, most of the time lots of knowledge are necessary to determine driver's status, even some knowledge are fuzzy and only can be reference[9]. It's essential to quantify the fuzzy knowledge and to unify quantifiable knowledge, and in order to use unified fatigue judgment criterion in driver fatigue model. The following driver fatigue judgment formula is applied in fatigue driving behavior model.

$$k = \sum_{i=1}^{n} \omega_i S_i \quad (1)$$

Here, K is the index of fatigue, its values is in [0, 1]. If its value is the closer to 1, it indicates that the higher the driver may be fatigue driving; if its value is closer to 0, it indicates the possibility of driver fatigue driving is lower, ωi is weight of i element in the driver fatigue factors, and Si is the fatigue status's valuesof the i factor.

3.3 The Model's Validation

To validate the model, two scenarios are designed to test the model's effectiveness, the following simulation experiments all set the time to the time period in prone to fatigue driving.

Firstly, a car is running on a straight highway, the vehicle speed is 120km/h. while the car moving, the operation interface prompts there is a left turn ahead with 165 degree angle (the angle, direction generated by model randomly). Under this circumstances, if the operator conduct 5 left-turn operations by key press, and conduct 5 right-turn operations after promotion of end of turn, the model does not show warning messages. However, if there is no turn operation after prompting message for a period of time (about 5 seconds), the model shows warning message "drowsiness".

Secondly, the car is also driving on a straight highway at beginning, and the vehicle speed is also set to 120km/h. After a period of time (about 10 minutes) there is no turning operation, and the the operator interface prompts that the vehicle deviate from its own lane right 10cm. At this moment, the operator conducts a substantial left-turn steering operation by using keyboard, and the model indicates driving warning message "insensitiveness" within a short time. By checking the road the car has passed, we know there are slight curve in the road, more than 10 minutes straight moving accumulation make the vehicle deviate from its own lane right 10cm. However, the operator does not adjust vehicle's moving direction according to road's slight curve. As finding the vehicle deviates from suitable lane, he takes a substantial steering wheel operation. Therefore, the model makes a judgment that the driver is in the status of "insensitiveness" [10].

The above two experimental results of fatigue driving behavior model simulation are consistent with fatigue driving situations.

4 Status Warning with Driver Fatigue Model

Based on vehicle performance's output, fatigue driving cognitive behavior model determine whether the driver is fatigue driving or which driving status he is. The model's output, which integrates with other model's output and control strategy, are developed into warning system. The warning system determine vehicle's and driving status, make decision, and finally notify vehicle's ECU (Electronic Control Unit) to implement the decision policy. Figure 1 is the framework for driving status monitoring and warning system including driver fatigue model.

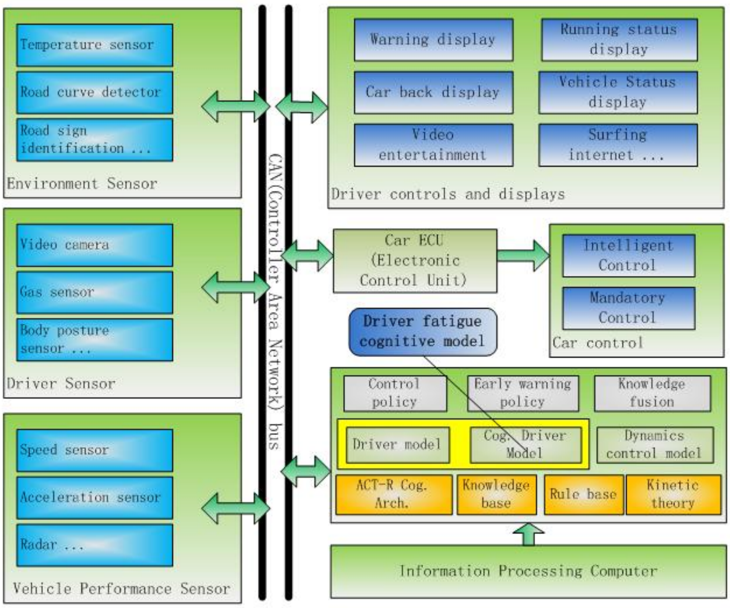

Fig. 1. The framework of driver status warning system

The sensor's data are collected over CAN (for controller area network) bus and transferred to the car operating system. Based on the information, which is collected and processed by sensor's control model, the policy model, database, rule base, knowledge, and intelligence being built on operating system, determine vehicle's and driving status and make decision, and then the decision policy is conducted by ECU. Finally, the system shows the result (warning), or takes measure (control), and achieves the purpose of driver's behavior monitor and driving status's warning [11].

5 Conclusion

The non-invasive driving fatigue detection method, which is on the basis of vehicle performance output and cognitive science theory, has significant advantages in monitoring of driving condition and early warning system. The results show that the output obtained from driver fatigue cognitive behavior model based on ACT-R are satisfactory. Based on analysis of literature and experimental result, the paper proposes the three stages standpoint for driver fatigue that corresponding to the stages that from the waking status to driver fatigue, it makes description of driver fatigue process more intuitive and effective, and lay the foundation of knowledge representation in ACT-R model for driver fatigue. In the light of the close relationship between research on driver fatigue and smart car, a general framework of the fatigue driver status monitoring and early warning system is proposed on the basis of traditional driving behavior model, driver cognitive behavior model, and vehicle dynamics control model.

This work is an ongoing part of the research on intelligent transportation system. Driver fatigue cognitive behavior model combining with other cognitive model, vehicle condition monitoring, and traditional driver model, all of these preliminarily establishes the core part of the driving status monitoring and early warning system.

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