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Research Article

Drivers' Fatigue Lane Departure Recognition

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Abstract: In order to enrich the judgment index of the lane departure and avoid a sensitive system which is caused by missing vehicle signals, a method of detecting fatigue lane departure based on human-vehicle-road characteristics has been proposed. At first, an experiment about fatigue lane departure has been taken. And then, relevant parameters that can reveal the human-vehicle-road characteristics are collected and analyzed, compared with that under normal lane changing. At last fatigue lane departure recognition model is constructed based on Gaussian Mixture-Hidden Markov Model (GM-HMM). The recognition results show good performance under online and offline tests.

Keywords: Fatigue, fatigue lane departure, lane departure warning, LCA, recognition, warning system

INTRODUCTION

The eSafety Forum (2005) attempted to calculate the benefit of lane changing monitoring systems used in Germany. The study estimates that implementation of the Lane Changing Assistance (LCA) system in vehicles would lead up to a 35% reduction in lane changing related accidents (a significant proportion of which were a result of fatigue), which would equate to a 2.9% reduction in all accidents.

Therefore, distinguished fatigue departure and normal lane changing has great important meaning, it helps increase reliability, reduce false alarm rates for LCA systems. There have been many studies on the detecting drivers' intentions and fatigue driver. Lethaus and Rataj (2007) has respectively collected the eye movement data of driver under four operating conditions, namely car-following, left lane changing, right lane changing and overtaking and has achieved the priority of eye movement versus the operating behavior of driver in timing sequence. Based on the Optimal Hidden Markov Model, Haijing (2013) has collected three parameters of head rotation, visual movement and vehicle movement. Based on the theory of Hidden Markov Model, Kuge *et al*. (2000) have established the lane changing behavior identification model. Under different observation parameters, different lane changing intention has different recognition rate, The recognition rate of correct lane changing intention by only collecting steering wheel angle is 85% and the recognition rate of lane keeping intention by collecting steering wheel rotation speed is 78.3%. Ahmed *et al*. (2014) based on fatigue symptoms (Eye closure, yawning, head tilting) to detect driver fatigue. Rogado *et al*. (2009) based on Heart Rate Variability (HRV), steering-wheel grip pressure, as well as temperature difference between the inside and outside of the vehicle, make possible to estimate in an indirect way the driver's fatigue level.

The previous researches have laid certain foundation for the engineering application of LCA, however, lacking focus to distinguish between fatigue lane departure and normal lane changing. Besides, these studies have used more complex techniques, too many physiological signals and identifying characteristics which are unclear. This makes the system difficult to apply in practice. In order to overcome these drawbacks, we introduce a method based on quantitative parameters and can easily be identified to distinguish between fatigue lane departure and normal lane changing. This makes the method simple and highly applicable in practice.

MATERIALS AND METHODS

Test design: According to the classification and inducing cause of driver's lane departure and for the purpose of avoiding actual vehicle test risk, the paper establishes a driver in the loop test bench based on CARSIM and LabVIEW visual programming software. The test bench designs the operating conditions of simulator according to the following two operating conditions, namely normal lane changing and fatigue departure, creates the driving ambient which will cause driver to make fatigue lane departure and normal lane changing, records the motion state of driver's face and

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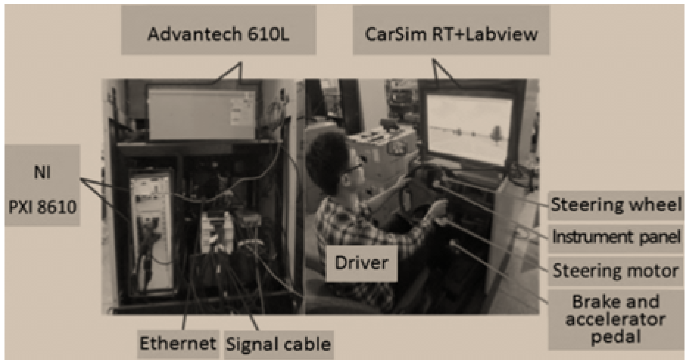

Fig. 1: Driving simulation platform

limbs through video equipment, filtrate the data of normal lane changing and fatigue lane departure and provides data support for the recognition of driver's fatigue lane departure.

Test elements: For achieving the test data of driver under different lane departure status, this research takes the driving simulator in the Laboratory of Automotive Simulation and Control of Jilin University as its core, chooses CarSimRT as its dynamic simulation software, makes the NIPXI8610 to collect the driver's operating signal of steering, steering lamp, accelerator pedal and brake pedal and transfer the signal to the Advantech 610L and adopts automatic gearbox in the upper computer vehicle model, which enables the vehicle to travel in any speed and traveling track under the control of driver. CarSimRT chooses C-class sedan, the structural parameter and dynamic parameter of vehicle are both set to default, the vehicle width is set to 1739 mm, the tire center distance is set to 1500 mm and the tire basic parameter is set to 205/55, R16. The test needs to satisfy the following three conditions, namely clear weather, leveled and dry road and traffic jam and shall guarantee that the test road environment is the same as the actual road environment to its utmost. Figure 1 shows the simulated test scene. 12 volunteers (8 male, 4 female) between 25-35 years (average age 30, average driving 3.5 years) are selected in the test to join the simulator test and all volunteers have achieved legal driving licenses. The test platform is as shown in Fig. 1.

Test procedure: Under the monotonous environment of simulator, the driver will enter into extreme fatigue status after 60 min of continuous driving or above.

For collecting test data of driver under fatigue status as much as possible, we implement the test by choosing the following three periods after breakfast, lunch and dinner, namely 9:00-10:00 A.M., 12:00-13:00 P.M. and 6:00-7:00 P.M. and each of the test lasts 1 h. For the purpose of eliminating the resuscitation effect on driver caused by complex driving task of lane changing, etc., no obstacle vehicle is set in the fatigue road scene. The test interludes the operating behavior of normal lane changing in the driving and collects the normal lane changing data under the status that the driver is sober and implementing single driving task.

Confirmation of recognition time window of fatigue lane departure: For accurately confirming the recognition time window of fatigue lane departure, the paper suggests the analysis method of combining the Receiver Operating Characteristic Curve (ROC) (Morris *et al*., 2011) on the basis of statistical analysis. The paper takes line pressing time as its benchmark, chooses the sample data of 1s, 2s, 3s, 4s and 5s before line pressing as its input data and makes assessment on the classification results of different time windows.

The results shows that the areas in the time slots before line pressing are 0.7235,0.7503, 0.8467, 0.7922 and 0.6077, among which, the normal lane changing UC (area under the curve) of 3s before line pressing is the largest, which shows that the recognition effect of the intention time window of 3s before line pressing is the best. By combining the statistical box plot of lane departure recognition time windows of the 12 drivers shown in Fig. 2, it is finally confirmed that the recognition time window of driver's lane departure is 3s.

Filtration of departure samples: By combining the test video and the vehicle lateral position parameters, the preliminary filtration of valid samples is implemented and the following principles can be considered during the final confirmation of departure samples:

- The steering wheel angle of simulator are left positive and right negative, so the preliminary classification of sample selection shall be implemented according to left departure and right departure.
- The departure status of driver shall be controllable and shall guarantee that no extreme abnormal phenomenon occurs on individual sample caused extreme departure.
- The speed of the filtrated sample shall be higher than 60 km/h.

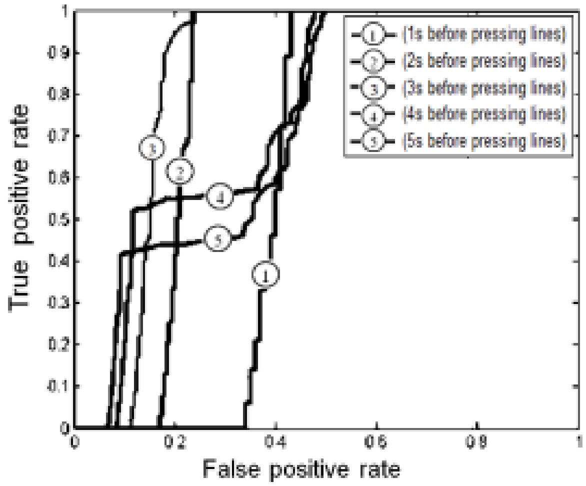

Fig. 2: ROC curve with different time windows

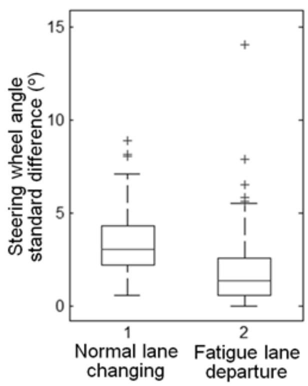

Fig. 3: Standard difference distribution of the steering wheel angle

According to the regulations above, 160 fatigue departure samples and 160 normal lane changing samples are finally filtrated.

The driver-vehicle-road characteristic analysis of fatigue lane departure means the summarization of the operating behavior of driver after fatigue departure, vehicle movement status and the changing rule of vehicle lateral positions. The following data have close connection with lane departure and can be directly achieved from simulator and actual vehicle, including steering wheel angle, steering wheel angle velocity, yaw velocity, lateral acceleration, vehicle lateral location and average lateral velocity.

Driver-vehicle-road characteristic analysis of fatigue lane departure:

Characteristic analysis of driver's operating behavior:

Steering wheel angle: We make statistical analysis on fluctuation which can reflect the steering wheel angle within a time period and the angle standard difference of dispersion degree and make analysis on all normal lane changing samples and fatigue lane departure samples. Results are shown in Fig. 3.

It can be seen that the one fourth quartile, median and three fourths quartile of the steering wheel angle standard differences are all larger than the relative value of fatigue departure. Through implementing independent sample T inspection on the normal lane changing and fatigue departure steering wheel angle standard difference and the relevant results are $p = 0.0001<0.05$, which shows that the steering wheel angle standard difference of normal lane changing is much greater than the fatigue departure. Therefore, there is great difference among the two values above, which can be taken as the characteristic parameter for distinguishing different lane departure status.

Steering wheel angle entropy: Steering wheel angle entropy (Steering Entropy) is proposed by a Japanese scholar Nakayama *et al*. (1999) and the research result shows that the steering entropy can be adopted in speculating the steering wheel operating stability of driver and can also be adopted in assessing the mental load of driver. The higher the entropy becomes, severer the operating and the higher the mental load becomes. The steering entropy implements its calculation according to the predicted deviation of steering wheel angle. The test implements statistical collection of all steering entropies of normal lane changing and fatigue lane departure.

From the Fig. 4, we can see that the steering entropy of fatigue departure is much smaller than the normal lane changing. Through implementing independent sample T inspection on the steering entropy of the fatigue departure and the steering entropy of normal lane changing and result is $p = 0.0001<0.05$, which shows that there is great difference between the fatigue departure angle entropy and the entropy of normal lane changing in statistical character. Therefore, the steering angle entropy can be taken as the characteristic parameter for distinguishing fatigue departure status.

Steering wheel angle velocity: This study adopts the standard difference of steering wheel angle velocity in analyzing the steering wheel rotation stability of driver. If the standard difference is great, then the rotation speed fluctuation becomes large and the driving stability becomes poor. Figure 5 shows the standard difference distribution of steering wheel rotation speed. On the whole, the standard difference of steering wheel angle velocity normal lane changing is larger than fatigue deviation.

Among the data above, independent sample T inspection is implemented on the standard difference of steering wheel angle velocity fatigue departure and normal lane changing and the result is $p = 0.002<0.05$, which shows that there is great difference between the

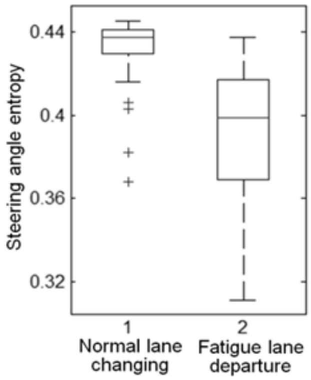

Fig. 4: Steering wheel angle entropy distribution

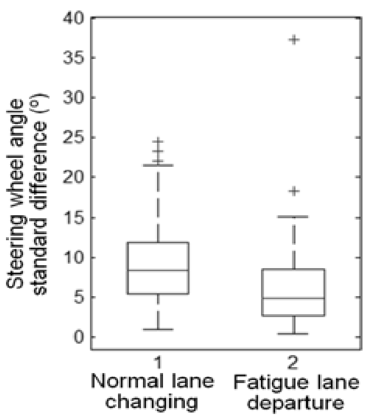

Fig. 5: Standard difference distribution of the steering wheel angle velocity

standard difference of steering wheel angle velocity of the two statuses, which shows that there is great difference between the two statuses. In conclusion, the steering wheel rotation velocity can be taken in distinguishing normal lane changing and fatigue departure.

Characteristic analysis of vehicle motion state:

Lateral acceleration: Through combining the lateral acceleration and the operating behavior character and regulation of driver, it can be inferred that the lane departure implemented by the driver is normal lane changing or fatigue lane departure. Analysis is implemented on the standard difference of vehicle lateral acceleration the two lane departure statuses by adopting the same statistical method from the above and Fig. 6 shows the result.

From Fig. 6, we can see that the standard difference of lateral acceleration of fatigue departure has great difference with the normal lane changing. After implementing independent T inspection, the significance accompanying probability $p = 0<0.05$, which shows that there is great difference between the two statuses. Therefore, lateral acceleration can be taken as the determining the basis of fatigue departure.

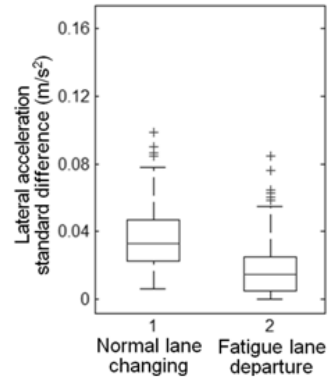

Fig. 6: Standard difference distribution of lateral acceleration

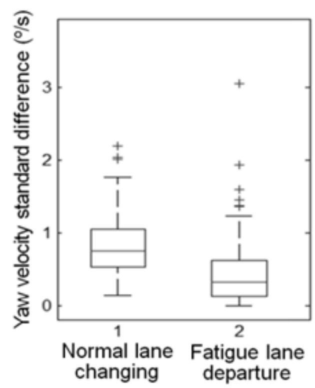

Fig. 7: Standard difference distribution of yaw velocity

Yaw velocity: We make analysis on the standard difference which can reflect the dispersion degree of yaw velocity and we find that the standard difference is great, which shows that the vehicle swinging frequency is high and the driver's adjustment of vehicle is more frequent. Results of the analysis are shown in Fig. 7.

From the observation, it can be seen that there is great difference between the standard difference of yaw velocity fatigue departure and the normal lane changing. After implementing independent T inspection, the significance accompanying probability $p = 0.013<0.05$, which shows that there is great difference between the two statuses. Therefore, yaw velocity can be taken as the determining basis of fatigue departure.

Characteristic analysis of relative motion between vehicle and lane line:

Lateral location of vehicle: Statistical analysis is implemented on average lateral location and the result is shown in Fig. 8. It can be seen that the average lateral location of normal lane changing status is mainly distributed in the area near 0.004 m and the fatigue departure is mainly distributed in the area near 0.003 m. After implementing independent T inspection on the two statuses, the result is $p = 0.007<0.05$, which shows that the average lateral location can be taken to distinguish fatigue departure and normal lane changing.

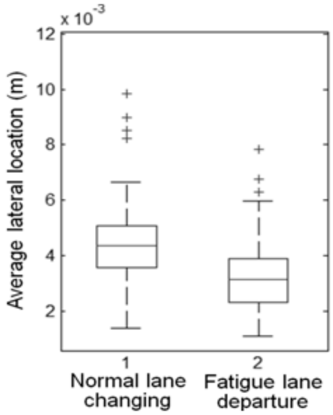

Fig. 8: Distribution of the average lateral location

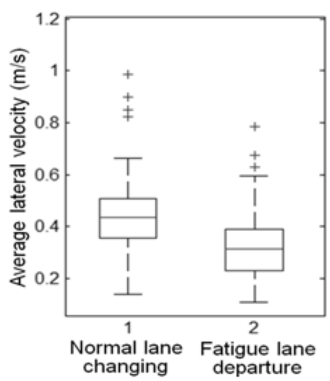

Fig. 9: Distribution of average lateral velocity

Average lateral velocity of vehicle: Average lateral velocity can reflect the fact that the vehicle is approaching towards the lane line in a fast speed, or the vehicle is approaching towards the lane line in a slow speed. The following Fig. 9 is the statistical analysis implemented on the average lateral velocity of all samples.

It can be seen that there is great difference between the fatigue departure and normal lane changing. After implementing independent sample T inspection on the two statuses, the result is $p = 0<0.05$, which shows that there is great difference in the lateral average speed during the departure procedure of the two statuses, which shows that average lateral velocity can be taken to distinguish normal lane changing and fatigue departure.

Recognition model building of fatigue lane departure: The main research target of this paper is to establish a mathematical model which can accurately recognize the fatigue lane departure behavior of driver and we adopt Gauss Hidden Markov Model (GM-HMM) to implement model building. According to the model building requirements of Hidden Markov, we need to filter the characteristic parameters through which we can infer the fatigue lane departure behavior. The characteristic parameters of model are finally confirmed according to the analysis result, so the characteristic parameters of normal lane changing model and fatigue departure model include the following 7 parameters, namely steering wheel angle, steering entropy, steering wheel angle velocity, lateral acceleration, yaw velocity, average lateral location and average lateral velocity.

RESULTS AND DISCUSSION

Model offline test: The procedure of model test means the procedure of putting the test samples into the model base and finds the predicted model which can best explain the present observation sequence, i.e., the assessment problem in HMM. During the classifier establishing procedure, the original data samples shall be separated into training set and test set, the training set is adopted in the model training and all of the remaining fatigue samples shall be taken to test the models. Furthermore, the test sample of normal lane changing model is added into the training set. Put the test set into the model base, assess the probability of the input observation sequence caused by normal lane changing model and fatigue departure model by combining forward algorithm and backward algorithm and the one with greater output probability is the corresponding predicted model of this observation sequence.

Classification scatter diagram is taken to show the recognition results achieved in different model bases. Result is shown in Fig. 10.

Among the results above, the accuracy of this recognition can be calculated by comparing the predicted test set classification result and the real test set classification result. The recognition accuracy of fatigue departure is 94.21%. The above analysis results show that the model recognition has good effect and high recognition confidence, which also show that it is an effective method to recognize the fatigue lane departure of driver by adopting GM-HMM.

Model online test: We implement offline analysis on the achieved test data, separate the data into training set and test set, which are applied in the training procedure and recognition procedure of GM-HMM established based on the analysis of the human-vehicle-road character of fatigue lane departure and achieves better recognition result. Fatigue lane departure identification process is as shown in Fig. 11.

For further verifying the effectiveness of model and improving the actual application effect of model, it is necessary to implement continuous analysis on the driver in the whole driving procedure, which needs to complete the online recognition of model. Transplant the modeling algorithm compiled basing on the MATLAB toolbox mentioned above to the driver in the loop test bench. Test data is achieved through CarSim and LabVIEW joint simulation and a section of data with time span of around 80s is cut from the follow-up

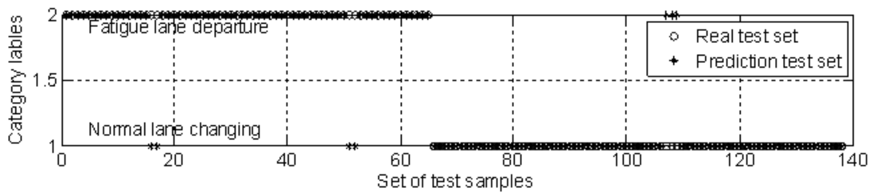

Fig. 10: GM-HMM based fatigue lane departure model recognition results

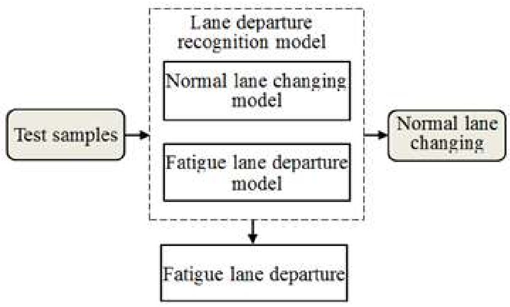

Fig. 11: Fatigue lane departure recognition based on GM-HMM

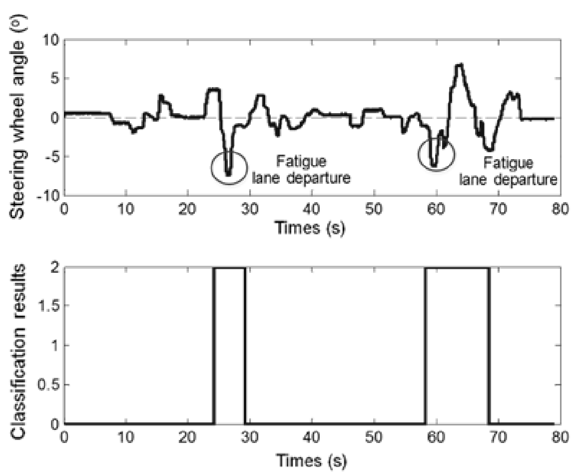

Fig. 12: Fatigue lane departure online recognition results; 0-lane keeping; 1-normal lane changing; 2-fatigue lane departure

fatigue departure test and is put into the recognition model base and the following Fig. 12 shows the result.

From Fig. 12, it can be seen that the predicted classification result basically agrees with the actual situation, which can satisfy the requirement of real-time recognition.

CONCLUSION

This study suggests the fatigue lane departure recognition method by considering the operating character of driver, the character of vehicle motion status and the relative motion character of lane line:

- According to the different incentives of fatigue lane departure, this study designs fatigue lane departure test and filtrates the characteristic parameters which can distinguish normal lane changing and fatigue departure according to correlation and significant difference.
- This study establishes fatigue recognition models based on Gauss Mixed Hidden Markov theory and achieves algorithm and completes the offline test and online verification of model by virtue of MATLAB. Offline test result shows that the fatigue departure recognition accuracy is 94.21%, which means that the method has a better recognition effect.

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