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DRIVER BEHAVIOR ANALYSIS AT THE TIME OF CROSSING PASS USING VEHICLE KINEMATIC MODEL AND GMM MODEL

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Abstract. *In recent years, traffic accidents have been increasing due to the popularization of the automobile and many of those accidents lead to death. For the safety of drivers and passengers, more and more research is done on vehicle safety, whether it be active safety or passive safety. At the moment, research on autonomous vehicles is gaining spotlight from the public. In most cases, a traffic accident is likely to occur at an intersection. As we know, driving behavior is different for each driver. So when a driver takes a turn at the intersection, by his own decision, there is an individual characteristic of the driving behavior. Thus, the coordinated operation of the steering wheel and pedals can be used to determine the individual characteristics of the driver. Therefore, in this study, using a stability factor and the analysis results of a GMM, we aim to evaluate cooperative operation, and encouraging results were obtained in our experiment.*
Keywords: Driving support systems, Driver characteristic, Gaussian mixture model, Stability factor

1. **Introduction.** An increase in the number of traffic accidents associated with the development of an automobile-based society supported by transportation network development and the spread of vehicles has been a big problem. In recent years, therefore, there have been advances in research on active safety devices for the purpose of preventing accidents, such as adaptive cruise control [1], and automatic braking function [2]. However, these systems cannot be said to be always effective because driving behavior and ability depend on the driver. For example, how safe the vehicle-to-vehicle distance and the vehicle speed feel to the driver varies depending on the driver. Additionally, the feeling for danger can be changed by body condition and the driving environment even when the driver is the same [3]. Therefore, in order to improve the individual compatibility of the safety support system to the driver's behavior and capabilities, it is important to be able to utilize the active safety device without discomfort.

In this study, our purpose is to analyze the individual characteristics of driving behavior, and construct a driver model that can be applied to safety support systems that considers the driver's individual characteristics. Generally, the driver operation is carried out through coordination of the operation of the steering wheel and pedals. In particular, coordination of the operation when turning left or right at an intersection is an important component of the individual characteristics of the driver's driving behavior. However, when turning right, behavioral elements such as looking at oncoming vehicles will increase, which can complicate driving behavior analysis. For simplicity, therefore, as a first step in this study, analysis of the cooperation of the driver's driving behavior will be limited to left turns.

So far, Ozawa et al. [4] represent driving behavior with a Gaussian mixture model (GMM), and have confirmed its effectiveness in extracting driver features. Imamura et al. [5] have also succeeded in estimating driver intention by using a GMM. In addition to the GMM, there is a kinematic model representing the motion state of the vehicle when turning left or right, which makes it possible to determine whether the vehicle is at risk of overturning by using it [7]. However, a research about driver's operation coordination by using the GMM and the kinematic model is not yet found.

In this study, we propose a new method to analyze the driver's operation coordination while turning left by using the GMM model. In addition, the vehicle state is analyzed at the same time by the vehicle kinematic model, and cooperative operation is attempted to be evaluated using the stability factor and the analysis result of the GMM.

2. Characteristics of Driving Behavior and Driver Models.

2.1. Characteristics of driving behavior. Usually, a driver operates a vehicle so that the vehicle behavior is within the confines of the driver's ability to sufficiently prevent accidents. However, it is able to operate the vehicle in a high accident risk condition, which is beyond normal driving behavior, and may be worsened by the condition of the driver's health. In addition, the range of normal operation capacity, related to the driver's driving ability and cognitive ability, can appear as a feature of the driving behavior in normal operation. Furthermore, differences during normal and abnormal operation are also considered to occur in the individual driver's operation. In this study, the individual driver's operation characteristics are considered and are represented by using a GMM model.

2.2. Gaussian Mixture Models (GMM). The GMM is a statistical model that is represented by a linear combination of several normal distributions [8], and is used in voice recognition and other areas. In addition, because the GMM is based on the normal distribution, the amount of calculation required is small, and it is suitable for low-performance real-time processing by personal computer.

The GMM consisting of M normal distributions can be represented in the distribution of each mixture weight α_m, mean vector $\boldsymbol{\mu}_m$, and the covariance matrix $\boldsymbol{\Sigma}_m$.

In this case, the output probability of the observation vector $\boldsymbol{o}$ is defined by the following equation.

$$P(\boldsymbol{o}|\alpha_m, \boldsymbol{\mu}_m, \boldsymbol{\Sigma}_m) = \sum_{m=1}^{M} \alpha_m N_m(\boldsymbol{o}), \tag{1}$$

where, α_m shows the weight of normal distribution number m, and it satisfies the following equation.

$$\sum_{m=1}^{M} \alpha_m = 1. \tag{2}$$

In addition, $N_m(\boldsymbol{o})$ shows the probability density function represented by the following equation.

$$N_m(\boldsymbol{o}) = \frac{\exp\left(-\frac{1}{2}(\boldsymbol{o} - \boldsymbol{\mu}_m)^t \boldsymbol{\Sigma}_m^{-1} (\boldsymbol{o} - \boldsymbol{\mu}_m)\right)}{(2\pi)^{\frac{D}{2}} |\boldsymbol{\Sigma}_m|^{\frac{1}{2}}}, \tag{3}$$

where, D shows the dimension of the observation vector $\boldsymbol{o}$, $|\boldsymbol{\Sigma}_m|$ shows the determinant of the covariance matrix, and $\boldsymbol{\Sigma}_m^{-1}$ shows the inverse matrix of the covariance matrix.

Recently, Imamura et al. [5] have proposed a method reflecting driver operation characteristics by using the GMM, and showed its effectiveness. In this study, the relationship

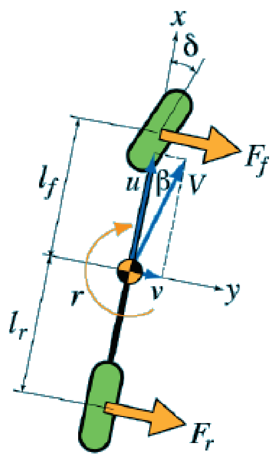


FIGURE 1. View showing a frame format of automobile model [7]

between cooperative operation of the pedals and steering wheel is modeled by using the GMM when turning left at an intersection.

2.3. **Vehicle kinematic model.** In order to express the motion of a vehicle in a strictly mathematical formula, very complex expressions are necessary. However, when considering only the basic rotational movement characteristic for the steering, it can be represented by a simplified kinematic model of planar motion of a rigid body, as is shown in Figure 1 [7]. In the kinematic model, when the vehicle is turning circularly at a constant steering angle, the lateral force that is applied to the tires is represented by parameter A called the stability factor and is shown in Equation (4).

$$A = \frac{\delta}{\omega l V} - \frac{1}{V^2}, \qquad (4)$$
$$\omega = \frac{1}{1 + AV^2}\frac{V}{l}\delta,$$

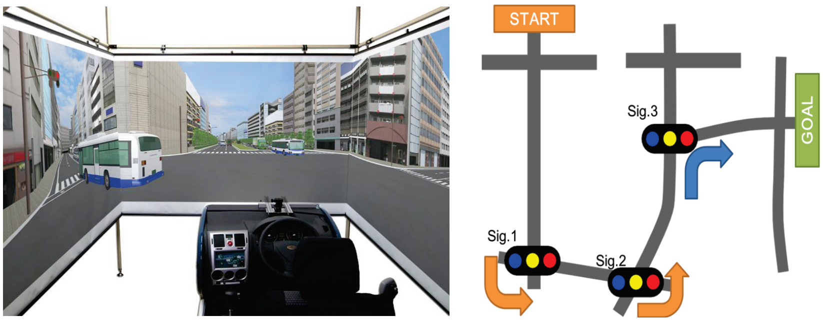
where ω [rad/s] is the angular velocity of the vehicle rotation when the vehicle is viewed from above, V [m/s] is the vehicle velocity, l [m] is the full vehicle length, and δ [deg] is the steering wheel operation angle. In addition, the vehicle state is said to be a steady circle turning state when the vehicle is turning in a circle with a constant steering angle and a constant speed. The radius of the circular turn can be defined as R, and is shown in Equation (5).

$$R = \left(1 + AV^2\right)\frac{l}{\delta}. \qquad (5)$$

As shown in Equation (5), when the vehicle is turning circularly at a constant steering angle, if $A > 0$ then the turning radius increases as the speed increases, and if $A < 0$ then the opposite happens where the turning radius decreases as the speed increases. That is, the risk increases as speed increases when a vehicle passes through the intersection. In other words, the required rotational radius becomes large as the speed increases, and the vehicle is likely to skid and overturn. The increase in the required rotational radius by Equation (5) is proportional to A, and therefore the necessary turning performance during a left or right turn can be evaluated by using A.

3. Driving Behavior Data Acquisition and Analysis.

3.1. Experimental environment and conditions. In this study, to control and construct a simulation environment, UC-win/Road 5.2 provided by FORUM8 Inc. has been installed. Figure 2(a) shows a photograph of the driving simulator (DS) constructed in this study. This is a very simple DS system consisting of a main computer, and 3 LCDs to produce the driver's view, a driver's seat and USB control devices. Therefore, it can be moved and transported to other places to perform experiments and demonstrations. The authors use this DS not only for experiments but also for demonstrations and safety instruction for educational use.



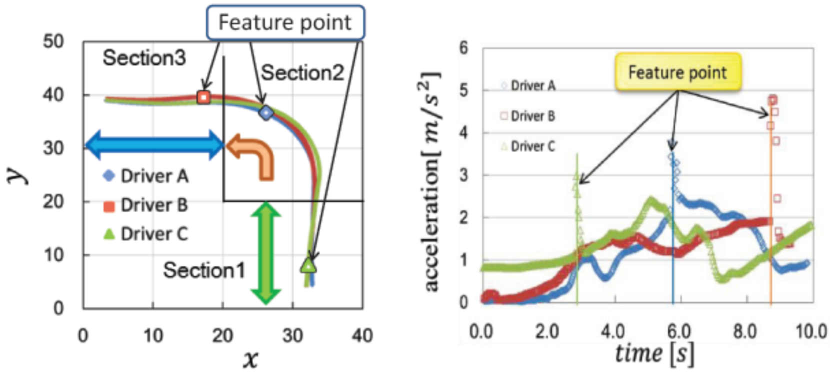
(a) Driving Simulator (b) Driving course Map

FIGURE 2. Photograph of the driving simulator and driving course map

UC-win is CAD (Computer Aided Design) software originally used for roads, urban views, etc. in the construction field. Therefore, it has rich design functions for terrain, roads, traffic lights, traffic flow patterns and structures provided by the 3D model. The driving simulation function works in software to confirm the designed environment and feelings of the driver of pedestrian views. Software updates improve reality and reliability of the simulator. The driver's environment is produced by three LCDs. Figure 2(b) shows an example of the driving course map designed. The driver can drive in the DS by using the gas pedal, brake pedal and steering wheel. The experimenters collect driving data at a sampling rate of 20 [Hz].

We carried out the following experiment for six subject drivers who gave their informed consent after they were given sufficient description of the experiment. The drivers are healthy 20- to 29-year-olds and have driving licenses. In order to obtain the operating data during natural operation by the drivers, the driving environment of the experiment mimics a city course that includes an intersection to perform one right turn and two left turns, and natural traffic flow, as shown in Figure 2(b). In order to decrease the variability between the subjects, the driving environment is controlled so that the subjects enter into the intersection after the vehicle stops at a red light. The driving test is performed with each subject three times, and the operating data are collected. Furthermore, in order to detect abnormal behaviors during operation, data collection while speeding was carried out in the same experimental environment. In this case, the traffic signal is not controlled, and the vehicle passes through the intersection at a speed of 40 [km/h] to reproduce dangerous driving.

3.2. Data analysis and estimation. Figure 3(a) shows an example of the vehicle trajectory when passing through the intersection by the three subjects and Figure 3(b) shows an example of vehicle acceleration by the same subjects. In Figure 3(a) the horizontal axis is the coordinate x and the vertical axis is the coordinate y. In Figure 3(b) the horizontal axis is the time [s] and the vertical axis is the vehicle acceleration [m/s^2]. In the case of the driving trajectory shown in Figure 3(a), there was no significant difference



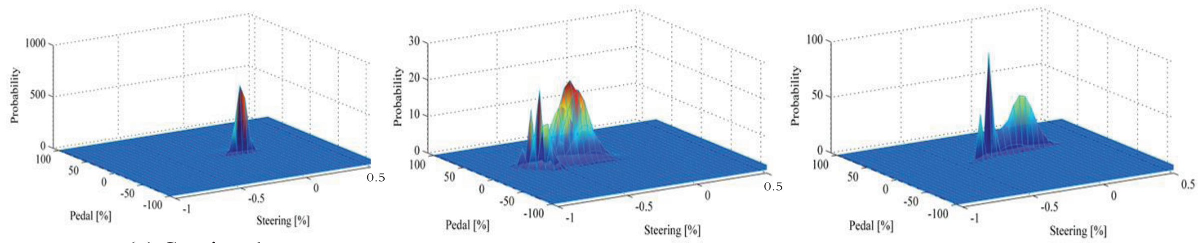
(a) Tracking data with feature point (b) Example of drivers acceleration

FIGURE 3. Example of traffic and acceleration data

between each subject, but in the case of the vehicle acceleration shown in Figure 3(b), the acceleration changes instantaneously and large differences between each subject can be observed. The change point is reproducible in the operation data of each subject, and it is believed to be operating characteristic of the subject individual. In this study, referencing the operational features shown above, left-turn is divided into three sections: Section 1 is from the intersection approach to the start of the turning curve point, Section 2 is during turning, and Section 3 is from the endpoint of the curve to the intersection end. A GMM is made of the operation in each section.

In this study, the speed, acceleration, steering angle and pedal data are extracted from the operating data of each subject, and a four dimensional (4D) GMM model of each subject at the time of passing the intersection is made. Figure 4 shows an example of the GMM constructed from the three sets of operation data of subject A, and is a simple two dimensional plot (pedal and steering operations) from the four dimensional GMM model. Figure 4(a) is the GMM of Section 1, (b) is the GMM of Section 2, and (c) is the GMM of Section 3.

It can be seen from the GMM model of subject A that in the case of the straight Section 1 shown in Figure 4, the distribution of the GMM has one peak in the direction of steering, the steering operation has almost been done, and the operation amount is concentrated around 0 at the frequency of more than 50%. In the case of Section 2, the largest individual difference is likely to occur and the steering and pedal operations are frequently performed. The distribution of the GMM has two peaks in the direction of the steering, one near 0.2% and another one near 0.6%. In the case of Section 3, which is a straight section, the distribution of the GMM also has two peaks in the direction of steering. The steering operation of the rightward direction is out relatively large, although it is a straight section as shown in Figure 4; therefore, it can be seen that it is a corrective action trajectory.



(a) Section 1 (b) Section 2 (c) Section 3

FIGURE 4. Example of the GMM at separate intersection (subject A)

TABLE 1. A and R/R_0 of driver A at each section

Course name	Section 1		Section 2		Section 3	
	A	R/R_0	A	R/R_0	A	R/R_0
Natural 1	0.12096	4.86293	0.04659	2.25549	0.01805	2.28368
Natural 2	0.07069	6.40625	0.05724	5.35885	0.10680	13.0395
Natural 3	0.06754	0.45840	0.05141	2.86754	0.01988	2.27534
Hurry 1	0.05288	**28.4896**	0.01963	2.69218	0.00703	2.41866
Hurry 2	0.03160	13.1389	0.10375	**26.4763**	0.01193	7.23815
Hurry 3	0.03318	13.8876	0.41281	**32.9082**	0.15485	**86.8654**

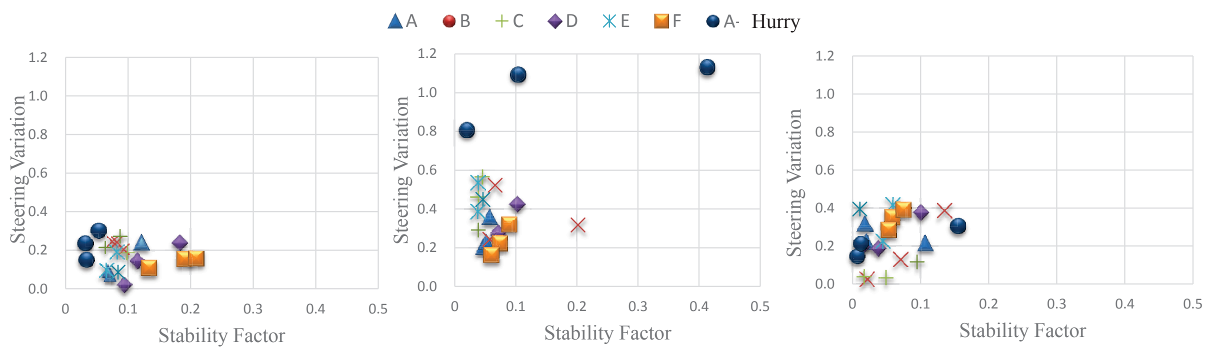
On the other hand, when the vehicle is turning circularly at a constant steering angle with speed V [m/s], the radius R of the circular turn can be shown by Equation (5). Here, when the velocity $V^2 = 0$, the vehicle's state is said to be very low-speed turning, and in this state there is no danger [7]. Then the turning radius R_0 can be obtained by Equation (5) during very low speed. Furthermore, the ratio of R and R_0 is calculated and the example of subject A is shown in Table 1, which is obtained by using the DS under experimental condition shown in Section 3.1. In each Section, the stability factor A at its highest point is taken and is shown along with R/R_0. It can be seen from Table 1 that in the case of natural driving, the R/R_0 values are at most about 10, and at the same time the A values are smaller than 0.1. Compared to this, in the case of hurried driving, the R/R_0 values are often greater than 20, and the A values are often greater than 0.1 at the same time.

Next, in order to evaluate the coordination of the subjects, a variation of the GMM distribution is defined by the following equation.

$$S = |M_2 - M_1| + \sigma_1 + \sigma_2. \tag{6}$$

Here, M is the mean value of one Gaussian distribution, and σ is the standard deviation of the distribution. And individual subject variation S was calculated for all the subjects and the results obtained were plotted against the stability factor A in Figure 5. Figure 5(a) is the result of Section 1, (b) is the result of Section 2, and (c) is the result of Section 3.

It can be seen from Section 1 that the variation in the steering operation is small and the stability factor A is around 0.1. Since Section 1 is nearly straight road, the driving operation of each subject is not much more, so the results shown in Figure 5(a) can be said to be reasonable. Compared to this, in the case of Section 2, the variation of the steering operation during natural driving is bigger than that of Section 1. In particular, in the



(a) Section 1 (b) Section 2 (c) Section 3

FIGURE 5. Example of the variation in the steering operation and stability factor (Driver A)

hurried driving of subject A, all three drives have much bigger variation of the steering operation, and the stability factor A in one drive is also bigger than 0.4. That is, in the case of hurried driving, the operation coordination can easily collapse, and when the speed is too fast the stability factor is high and the vehicle has a higher likelihood of overturning. In the case of Section 3, the variation in the steering operation is smaller than that of Section 2, but is bigger than that of Section 1, although the stability factor A is around 0.1. This is because there is not much driving behavior on the straight road immediately after leaving the turn, and the speed does not increase enough, so the stability factor A is low. From the above discussion, the evaluation of cooperative operation by using the analysis results of the stability factor and the GMM model can be said to be useful.

4. **Conclusion and Remarks.** In this study, we have analyzed the driver's operation coordination during left turns by using the GMM model and the stability factor A. In order to achieve our purpose, a parameter of the variation of the GMM distribution was defined. Furthermore, individual subject variation was calculated for all the subjects and the results obtained were plotted against the stability factor A.

The obtained results show that in the hurried driving of subject A, all three drives had much bigger steering operation variation, and the stability factor A in one drive was also bigger than 0.4. That is, in the case of hurried driving, the operation coordination of the operations could easily collapse, and when the speed was too fast, the stability factor was high and the vehicle had a higher likelihood of rolling over. In the future, by using our proposed method, more experimental data will be analyzed and a driver model will be constructed.

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