Mobility Force Model for Microscopic Simulation of Motorcycle Traffic Behavior

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Abstract—**This paper presents the conceptual structure of a novel microscopic traffic flow behavior simulation model for motorcycle traffic based on a mobility force structure, called mobility force car-following model. The mobility force is defined as the interactive force of motorcycle by surrounding vehicles and environment of lane layout. The kinetic behavior of the motorcycle will be induced and constrained by the force created due to the spaces surrounding. The concept is to describe the driving behavior using a series of forces of the attraction and repulsion related to the vehicle and spaces surrounding in front of the motorcycle. The model can describe both of the lateral motion and longitudinal motion in views to the motorcycle driving feature. Through a series of calibration for the parameters of the model, the regression statistical significance and the validation of the model output using the field survey data, the results illustrated the enough accuracy of the result of model output. The model is then verified to be suitable to describe the real motorcycle driving behavior preliminarily.**

Keywords-car-following model; mobility force; force field; microscopic simulation; motorcycle

I. INTRODUCTION

Traditional car-following model assumed vehicles only move along a line within the lane following to the front vehicle, while not doing lane change. The car following models explained the motion of vehicles basically only in one dimension. The vehicle will react to the front vehicle under the stimulus by front vehicle basing on the distance and relative speed etc, such as in the GM car-following model. However, for the traffic with high composition of motorcycles, the driving behavior responses to the possible space in front of the vehicles. The vehicle driving behavior, especially regarding motorcycle, will be influenced not only by the front car, but also by the car surrounding it nearby, and nevertheless by the width of lane and the lateral clearance. Therefore, this paper is newly to create a novel car-following model under consideration of all the spaces both longitudinal and lateral surrounding the motorcycle. The idea originally comes from the concept of force field interactive between the space and vehicles. Therefore, it is named as Mobility Force Model.

II. CONCEPTUAL STRUCTURE OF MOBILITY FORCE MODEL

A. Basic Concept

In the past, Hsu etc., had proposed a car-following behavior model based on the concept of Newton's law of universal gravitation, called "gravitational car-following model" [1]. Under the assumption of car driving behavior of pursuing the fast speed as possible to achieve desired speed, the vehicle will always want to move to the space where no vehicles occupied, and it avoids collision with other vehicles. Therefore, the surrounding not occupied space in front of the car will create an attraction force to push the vehicle move to that position as soon as possible. The attraction force concept is then generated. Though the calibration of the parameters using field survey data, the accuracy is not acceptable with respects of statistics significance. However, the force field concept could be a possible direction for developing advanced car-following model. On the other hand, Helbing created a social force model to describe the pedestrian walking behavior [2]. It takes the pedestrian walking behavior as the result of the interactive force between the pedestrian based on the territory impact on the force to move the pedestrian. The social force model becomes then the practically successful model using in microscopic simulation software VSSIM. In this paper, the motorcycle driving behavior could be seen as similar reaction of force impact, but motorcycle has the mobility and should be constrained by acceleration and deceleration ability of motorcycle and safety concern of motorcyclist. Therefore, referring to the social force model and the force field interactive concept, a Mobility Force Model is then proposed at this research. If there is a vehicle which impedes the vehicle to move ahead under the limit of the distance, it will cause a repulsive force to stop the vehicle or reduce its speed accordingly. The vehicle will drive with the resulted acceleration affected by the force. However, there are a number of forces which influence the acceleration or deceleration at the same time. The driving behavior will be affected by the total force. The forces are generated by the space in front the vehicle or next to the vehicle. Therefore, at least, it supposes there are at least four forces affecting driving, as illustrated in Figure 1, which are:

1. Desired speed attraction force to move forwards, such as the difference between desired speed and present speed, F_d;
2. Interaction force by other vehicles surrounding nearby F_i, including which will obstruct following vehicle to move forwards, F_f and attraction force generated by of lateral space from the car by the next, F_n;
   Repulsive force by the lane marking for lane keeping, F_l.
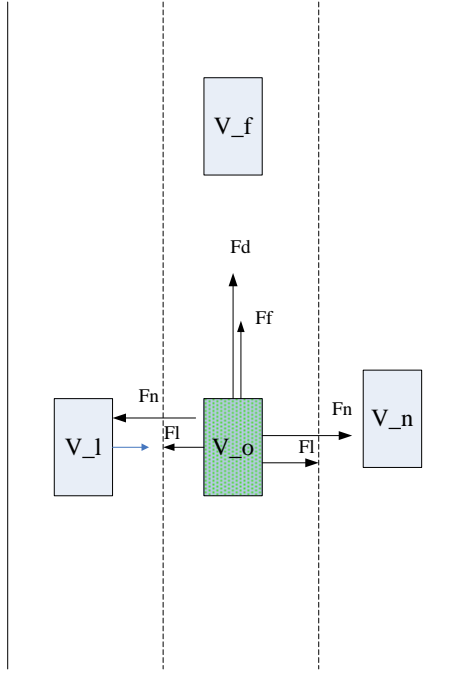
FIGURE I. FORCES OF DRIVING FORCE FIELD

B. Desired Speed Force

The desired speed attraction force F_d is a longitudinal force caused by the attraction force for vehicle to achieve the desired speed. The force equation of F_d is as follows.

$$\overrightarrow{f}_\alpha^d(t) = \frac{1}{\tau_\alpha}(v_\alpha^d(t)\overrightarrow{e}_\alpha - \overrightarrow{v}_\alpha(t))$$

(1)

where $\overrightarrow{f}_\alpha^0(t)$ is desired speed force of the driver α influenced by desired speed $v_\alpha^d(t)$ and the expected driving direction $\overrightarrow{e}_\alpha$, spot speed $\overrightarrow{v}_\alpha(t)$ and reaction time τ_α.

C. Interaction Force

The strength of the interaction force Fi will be influenced by the distance and the driver vision angle change. The interaction force Fi can be denoted as combination of two parts as following equation.

$$\overrightarrow{f}_{\alpha\beta}(t) = w(\theta_{\alpha\beta})\overrightarrow{g}(\overrightarrow{r}_{\alpha\beta}(t))$$

(2)

where the $\theta_{\alpha\beta}$ is the angle between in front vehicle β and the observed vehicle driver α, and the $\overrightarrow{r}_{\alpha\beta}(t)$ is the relative position of α and β at t time point.

$$\overrightarrow{r}_{\alpha\beta}(t) = \overrightarrow{r}_\alpha(t) - \overrightarrow{r}_\beta(t)$$

(3)

where the $\overrightarrow{r}_\alpha(t)$、$\overrightarrow{r}_\beta(t)$ are the position dimension of α and β, as shown in following Figure 2.
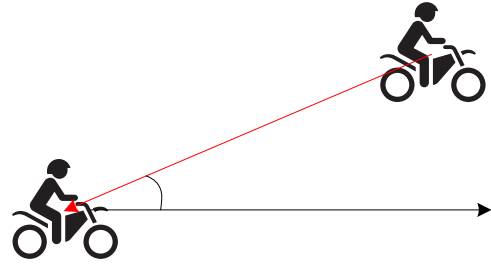

FIGURE II. THE RELATIVE POSITION OF THE VEHICLES

The $w(\theta_{\alpha\beta})$ is the angle weight to denote the impact of the front vehicle on the driver. The interaction force is inversed with the distance, and denoted as $\overrightarrow{g}(\overrightarrow{r}_{\alpha\beta}(t))$.

$$\overrightarrow{g}(\overrightarrow{r}_{\alpha\beta}(t)) = -\nabla_{\overrightarrow{r}_{\alpha\beta}} V_{\alpha\beta}(\overrightarrow{r}_{\alpha\beta}(t))$$

(4)

where $V_{\alpha\beta}$ is the interaction force field. The force field is described as an ellipse shape field as illustrated in Figure 3. When the speed difference dv between these two vehicles is zero, where exits a basic force field as shown in Figure 3.a, otherwise there is the relative force field as shown in Figure 3.b.
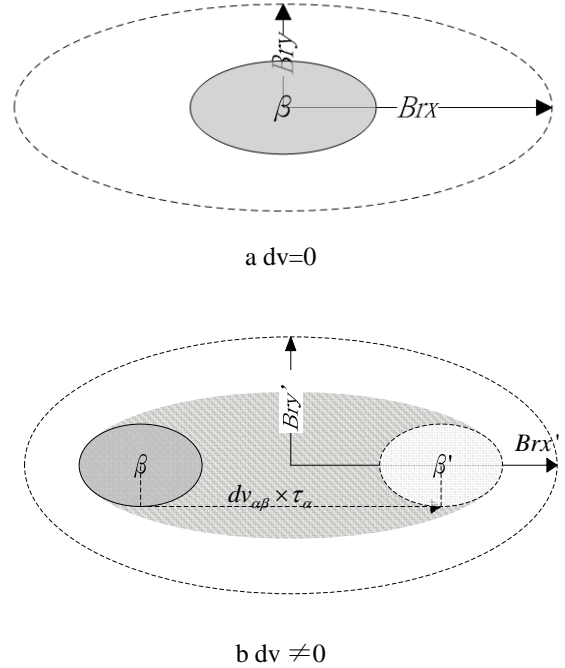

a dv=0

b dv $\neq$ 0

FIGURE III. INTERACTION FORCE FIELD

Combining with the speed difference and the distance into the ellipse force field dimension, the interaction force Fi is then as following equation. Its parameters requested being calibrated are listed in Table 1.

TABLE I. THE PARAMETERS OF THE INTERACTION FORCE FIELD

$\vec{r}_{\alpha\beta}(t)$	Relative position between the driver α and vehicle β at t.
$d\vec{v}_{\alpha\beta}(t)$	Relative speed difference between the driver α and vehicle β at t.
a, b	The size of motorcycle and car
τ_α	Reaction time of driver α
λ	Angle weight of driver α, parameter
A_r	Strength of interaction force, parameter
B_{rx}	Influence range of longitudinal interaction force, parameter
B_{rx}	Influence range of lateral interaction force, parameter
C_r	Adjustment constant between attractive force and repulsive force, assumed as 2

D. Curb Lane Marking Force

For the vehicle to drive on the curb lane, it should be constrained by the space closing to the lane marking for keeping safety side clearance. The force by curb lane marking F_l is illustrated in Figure 4.
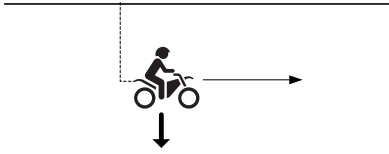

FIGURE IV. FORCE BY CURB LANE MARKING

$$\vec{f}_{\alpha B}(\vec{r}_{\alpha B}(t)) = -\nabla_{\vec{r}_{\alpha B}} U_B(|\vec{r}_\alpha - \vec{r}_B|) \quad (5)$$

where the distance to the curb is $\vec{r}_{\alpha B} = \vec{r}_\alpha - \vec{r}_B$, $\vec{r}_\alpha$ is the position of driver α and $\vec{r}_B$ is the position of curb lane marking, U_B is the force field.

$$U_B(\vec{r}_{\alpha B}(t)) = A_U e^{-|\vec{r}_{\alpha B}(t)|/B_U} \cdot \frac{\vec{r}_{\alpha B}(t)}{|\vec{r}_{\alpha B}(t)|} \quad (6)$$

The parameters needed to be calibrated are listed in Table 2.

Table 2 the Parameters of lane marking force.

$\vec{r}_{\alpha B}(t)$	Relative position of driver α to the lane marking at time t.
A_U	Strength of the lane marking force, parameter
B_U	Range of the lane marking force field, parameter

III. CALIBRATION OF MODEL PARAMETERS

Using the maximal likelihood method, the parameters of the model are calibrated by referring the method addressed by Hoogendoorn [3].

A. Maximal Likelihood Function

The model with the random error item can be denoted as following equation.

$$\vec{a}_\alpha(t+\tau) = \vec{f}_\alpha(\vec{v}_\alpha(t), \vec{r}_\alpha(t) - \vec{r}_\beta(t),...|\theta_\alpha) + \vec{\varepsilon}_\alpha \quad (7)$$

where $\vec{a}_\alpha$ is the acceleration resulted from the total force, $\vec{f}_\alpha$ is the model content of force and θ_α denotes the set of all parameters, the $\vec{\varepsilon}_\alpha$ is the random error item which is assumed to follow normal distribution with mean 0 and standard deviation of . Through a field video survey, the data of position, relative distance and speed difference would be taken to calibrate the parameter set θ_α.

$$L_k(\theta_\alpha, \sigma_\alpha) = \frac{1}{\sigma_\alpha\sqrt{2\pi}} e^{-\frac{\left(\vec{a}_\alpha^{obs}(t_k+\tau) - \vec{a}_\alpha(t_k+\tau)\right)^2}{2\sigma_\alpha^2}} \quad (8)$$

$$\vec{a}_\alpha(t_k+\tau|\theta_\alpha) = \vec{f}_\alpha(\vec{v}_\alpha^{obs}(t), \vec{r}_\alpha^{obs}(t) - \vec{r}_\beta^{obs}(t),...|\theta_\alpha) \quad (9)$$

The likelihood function L_k of each time step of traffic flow is as equation (8), where the $\vec{a}_\alpha^{obs}(t_k+\tau)$ is the real observed acceleration rate, $\vec{a}_\alpha(t_k+\tau)$ is the model estimated acceleration rate as equation (9), which is dependent on the value of parameter θ_α. Using the data of n time steps, the likelihood estimator is as follows:

$$L = L(\theta_\alpha, \sigma_\alpha) = \prod_{k=1}^n L_k(\theta_\alpha, \sigma_\alpha) \quad (10)$$

$$\ln L(\theta_\alpha, \sigma_\alpha) = -\frac{n}{2}\ln(2\pi\sigma_\alpha^2) - \frac{2}{2\sigma_\alpha^2}\sum_{k=1}^n \left(\vec{a}_\alpha^{obs}(t_k+\tau) - \vec{a}_\alpha(t_k+\tau|\theta_\alpha)\right)^2 \quad (11)$$

$$\frac{\partial \ln L}{\partial \sigma_\alpha^2} = 0 \Rightarrow \hat{\sigma}_\alpha^2 = \frac{1}{n}\sum_{k=1}^n \left(\vec{a}_\alpha^{obs}(t_k+\tau) - \vec{a}_\alpha(t_k+\tau|\theta_\alpha)\right)^2 \quad (12)$$

$$\ln L(\theta_\alpha, \hat{\sigma}_\alpha) = -\frac{n}{2}\ln\left(\frac{2\pi}{n}\sum_{k=1}^n \left(\vec{a}_\alpha^{obs}(t_k+\tau) - \vec{a}_\alpha(t_k+\tau|\theta_\alpha)\right)^2\right) - \frac{n}{2} \quad (13)$$

$$\hat{\theta}_\alpha = \arg\max \ln L(\theta_\alpha, \hat{\sigma}_\alpha) \quad (14)$$

B. Results of Parameter Calibration

Using a video survey and image processing technique, the field observed traffic flow microscopic data are used to calibrate the parameter of the model. Table 3 lists the input variable values for modelling. The values come out through the field survey. Table 4 illustrates all the input constant and calibrated parameters

TABLE III. INPUT VARIABLE VALUE OF THE MODEL

Driver parameter		
$\mu(v_{\max}^d)$	Mean for Maximal desired speed distribution	14.96 m/s
$\sigma(v_{\max}^d)$	Standard deviation for Maximal desired speed distribution	3.55 m/s
τ	Reaction time	1 s
C_r	Adjustment constant between attractive force and repulsive force	2
Size parameter of vehicle		
a_m	Size parameter of motorcycle	1.2 m
b_m	Size parameter of motorcycle	0.5 m
a_c	Size parameter of car	2.5 m
b_c	Size parameter of car	1.9 m

TABLE IV. CALIBRATION RESULTS OF PARAMETERS

Desired speed force		
C	Constant of initial desired speed	1.77
Lane marking force		
A_U	Strength of the lane marking force, parameter	1.87 m/s2
B_U	Range of the lane marking force field, parameter	1.80 m
Interaction force		
λ	Angle weight of driver α	0.11
A_{rm}	Strength of interaction force of motorcycle	0.63 m/s2
B_{rmx}	Influence range of longitudinal interaction force of motorcycle	2.11 m
B_{rmy}	Influence range of lateral interaction force of motorcycle	1.37 m
A_{rc}	Strength of interaction force of car	1.41 m/s2
B_{rcx}	Influence range of longitudinal interaction force of car	4.78 m
B_{rcy}	Influence range of lateral interaction force of car	2.32 m

IV. VALIDATION OF MODEL

Using the model, for validating the accuracy of the model, a simulation program is created to conduct the simulation of the field survey traffic flow, and then using the simulation results to compare with the field survey data to validate the model accuracy. According to the value of RMSE 以及 MAPE, the results as illustrated in Table 5 show the accuracy of model applied to simulate the real traffic flow is acceptable.

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(V^{sim} - V^{obs}\right)^2} \tag{15}$$

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\left|(V^{sim} - V^{obs})\Big/V^{obs}\right| \times 100\% \tag{16}$$

where N : simulation time steps, V^{sim} : output of simulation, V^{obs} : field survey value.

TABLE V. THE VALIDATION RESULTS OF RMSE AND MAPE

	speed(m/s)	Diving direction angle
RMSE	2.78	4
MAPE	33.8%	3%

V. CONCLUSION AND SUGGESTION

Using the force field concept, the mobility force model is developed in this paper through a preliminary calibration and validation process. The model is expected to enhance the simulation ability to simulate the complex driving behavior of motorcycle mixed traffic in the future.

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