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An Approaching Index to Evaluate a forward Collision Probability

Yuan-Lin Chen

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***Abstract*—**This paper presents an approaching forward collision probability index (AFCPI) for alerting and assisting driver in keeping safety distance to avoid the forward collision accident in highway driving. The time to collision (TTC) and time headway (TH) are used to evaluate the TTC forward collision probability index (TFCPI) and the TH forward collision probability index (HFCPI), respectively. The Mamdani fuzzy inference algorithm is presented combining TFCPI and HFCPI to calculate the approaching collision probability index of the vehicle. The AFCPI is easier to understand for the driver who did not even have any professional knowledge in vehicle professional field. At the same time, the driver's behavior is taken into account for suiting each driver. For the approaching index, the value 0 is indicating the 0% probability of forward collision, and the values 0.5 and 1 are indicating the 50% and 100% probabilities of forward collision, respectively. The AFCPI is useful and easy-to-understand for alerting driver to avoid the forward collision accidents when driving in highway.

***Keywords*—**Approaching index, forward collision probability, time to collision, time headway.

I. Introduction

THE forward collision accident is a serious issue in the world and there are so many researchers who devoted efforts to avoid forward collision technology [1]-[24]. It is very important to avoid the forward collision accidents in highway driving, and the modern cars are equipped with all kinds of measuring and warning system for assisting drivers driving in safety condition. A well known product, Advanced Driver Assistance Systems, is produced by Mobileye company [24] to avoid the forward collision accidents.

Nakaoka et al. [1] presented a forward collision warning algorithm based on road friction coefficient and driver characteristics. The presented algorithm used the critical warning distance as a factor to determine the collision warning signal. Liu et al. [2] developed an advanced driver assistance system with lane departure warning and forward collision warning functions. They used a CMOS camera to acquire roadway image in front of driving car. In [7], the vehicle control for collision avoidance was studied with two control objectives, i.e. minimization of the safety distance error and regulation of the relative velocity between two vehicles. A dynamic collision avoidance component for the vehicle following approach was presented by Gehrig and Stein [8]. The elastic-band approach was used for avoiding collision event. Cabrera et al. [10] presented two time-based measures for assessing both front and rear collision threats. The paper focuses on deceleration behavior which involves both gas pedal releasing and brake pedal depressing during on the car following driving. Berthelot et al. [12] used the time metrics such as TTC, time-to-brake (TTB) and time-to-react (TTR) to measure the assessing the risk potential of traffic situation. Ovcharova et al. [13] presented a preliminary study of different visual acoustical human-machine interface (HMI) concepts performed in a driving simulator.

The salient features of this paper are summarized as follows: (1) The TTC factor is used to evaluate a forward collision probability called an TFCPI; (2) The TH factor is designed to build a forward collision probability called an HFCPI; (3) An approaching index, AFCPI, which is evaluated from the combination of TFCPI and HFCPI, is presented for alerting the drivers to avoid the forward collision accidents.

Yuan-Lin Chen is with the Ming Chi University of Technology, New Taipei City, Taiwan (e-mail: chenyl@mail.mcut.edu.tw).

II. Driver Behavior Analysis

A. Reaction Time and Braking Action

The reaction time is the action response time when driver met an event. The distance traveled by vehicle during the reaction time is called the reaction distance. The reaction time can be divided into three components which are the reflection time, judgement time, and action time. The reaction time varies in the range between 0.64 and 1.04 s [16].

B. Time to Collision, TTC

The definition of TTC could be expressed as (1)

$$TTC=D(t)/V_D \tag{1}$$

where D(t) is the distance between driving vehicles. The V_D is a velocity between the following vehicle and the ahead vehicle as shown in (2)

$$V_D=V_F-V_A \tag{2}$$

where V_F is the velocity of the following vehicle and V_A is the velocity of the ahead vehicle. $V_D \leqq 0$ means that the driving vehicles is driving in safety condition. On the other hand, $V_D \geqq 0$ means that it will cause a forward collision after TTC. Zhang et al. mentioned that the critical TTC value could be set as 1.5 s [11].

C. Time Headway, TH

The definition of the TH was defined as (3). In general case, the value of TTC is greater than or equal to TH. If the speed of the ahead vehicle is zero, then the values of TTC are equal to TH.

$$TH = D(t)/V_F \tag{3}$$

Wang et al. [15] described that the car-following scenario on the highway has 2% which keeps on TH=0.8 s, 11% which keeps on TH=1 s, 24% which keeps on TH=1.2 s, 23% which keeps on 1.4 s, and 14% which keeps on TH=1.6 s. In summary, the drivers keep the car following under the value of TH=0.8 s. It means that the distance between driving cars is about 22.2 m under 100 km/h speed of the following vehicle.

III. An AFCPI

A forward collision probability index (FCPI) is presented by the author [19]. In this paper, an AFCPI, which is evaluated from a TFCPI and an HFCPI, is presented for alerting the drivers to avoid the forward collision accidents. At the same time, the driver's behavior was taken into account to build the forward collision probability index.

For the probability index, the driver could understand easily the meaning of the index. A 100% value of the index means the vehicle with a 100 percent for the collision under driving situation. On the other hand, a 0% value of the index means the driving in safety status. If the index value is 20%, it means that the driving collision probability is 20%.

- *TTC Forward Collision Probability Index (TFCPI)*

A Z-shaped membership function was designed to model a forward collision probability index which is related to TTC and presented as the following equation

$$f(TTC,a,b) = \begin{cases} 1, & TTC \le a \\ 1 - 2\left(\frac{TTC-a}{b-a}\right)^2, & a \le TTC \le \frac{a+b}{2} \\ 2\left(\frac{TTC-b}{b-a}\right)^2, & \frac{a+b}{2} \le TTC \le b \\ 0, & TTC \ge b \end{cases} \tag{4}$$

where a=$TTC_{critical}$ and b=TTC_{set}.

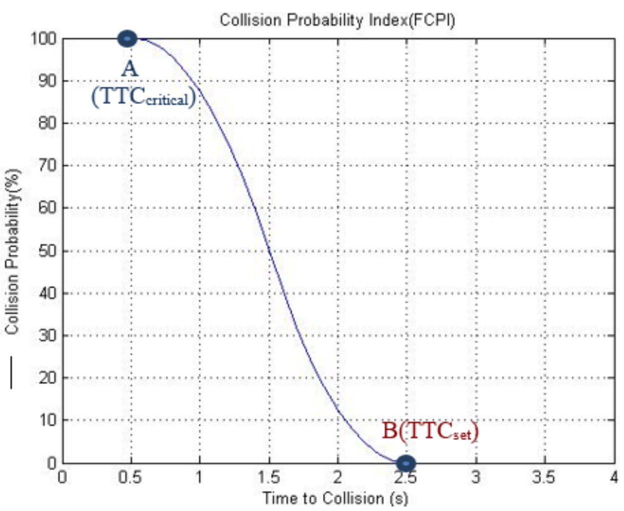

Fig. 1 Relationship between the forward collision probability and TTC with Z-shaped membership function

Zhang et al. [11] presented three warning levels based on the TTC for forward collision warning system. When TTC is smaller than 0.5 s, it is a dangerous situation and a braking commend is needed for avoiding a forward collision accident. It is a safety driving condition when TTC is greater than 2.5 s. It must warn the driver to pay attention when TTC is smaller than 2.5 s.

In this paper, we use a Z-shaped membership function, as (4), to build the forward collision probability index as shown in Fig. 1. At the same time, we present a self-learning algorithm to determine the points A and B in Fig. 1. The setting points A and B considered the driver's behavior to build the collision probability index function.

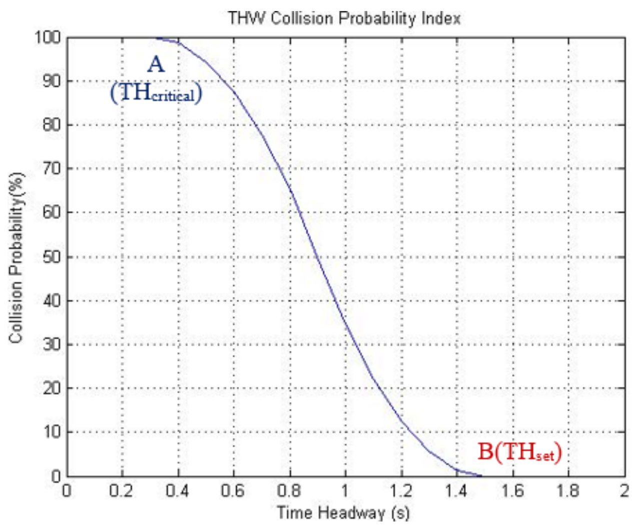

Fig. 2 Relationship between the forward collision probability and TH with Z-shaped membership function

- *TH Forward Collision Probability Index(HFCPI)*

The value of TH indicated the following distance between the driving cars. Wang et al. [15] described that most of drivers keep the TH greater than 1 s when driving in highway. According to the observation of the paper [15], the point B set to be 1.5 s is a good design. When TH is greater than 1.5 s, the forward collision probability is set to be 0. It is a safety driving condition when TH is greater than 1.5 s. When TH is smaller than 0.3 s, it is a dangerous situation and the collision probability indicated 100% for alerting the driver. It must warn the driver to pay attention when TH is smaller than 1.5 s. A Z-shaped membership function was designed to model a forward collision probability index which related to TH and presented as (5). Fig. 2 shows the relationship between the forward collision probability and TH with Z-shaped membership function. Again, we use a self-learning algorithm to determine the points A and B in Fig. 2.

$$f(TH,a,b) = \begin{cases} 1, & TH \le a \\ 1 - 2\left(\frac{TH-a}{b-a}\right)^2, & a \le TH \le \frac{a+b}{2} \\ 2\left(\frac{TH-b}{b-a}\right)^2, & \frac{a+b}{2} \le TH \le b \\ 0, & TH \ge b \end{cases} \tag{5}$$

where $a=TH_{critical}$ and $b=TH_{set}$.

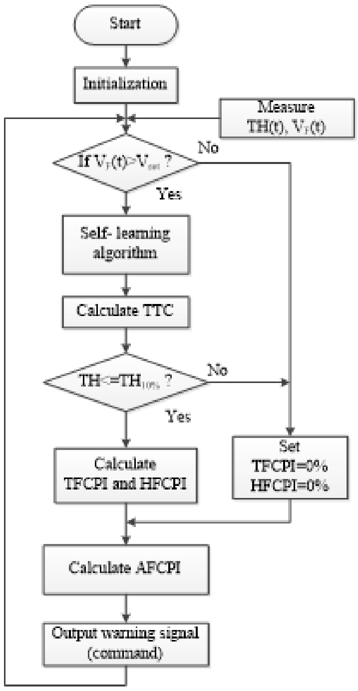

Fig. 3 A flowchart of the forward collision warning algorithm

- *An AFCPI*

The Mamdani-type fuzzy inference system [25] is used to evaluate the AFCPI. Equation (6) expresses the AFCPI which is combined from TFCPI and HFCPI.

$$u_{AFCPI}(TTC,TH) = probor[u_{TFCPI}(TTC), u_{HFCPI}(TH)] \quad (6)$$
$$= u_{TFCPI}(TTC) + u_{HFCPI}(TH) - u_{TFCPI}(TTC)u_{HFCPI}(TH)$$

The TTC and TH are the most important factors in forward collision issue. Equation (6) could merge the effects of TTC and TH. The following examples demonstrate the performance of the AFCPI index.

Example 1. When $u_{TFCPI}(TTC)$ =1.0 and $u_{HFCPI}(TH)$ =0.5 then

$$u_{AFCPI}(x) = 1.0 + 0.5 - 1.0\text{x}0.5 = 1.0$$

When one of the indices reaching 100% probability to have a forward collision, AFCPI is equal to 100%.

Example 2. When $u_{TFCPI}(TTC)$ =0.5 and $u_{HFCPI}(TH)$ =0.5 then

$$u_{AFCPI}(x) = 0.5 + 0.5 - 0.5\text{x}0.5 = 0.75$$

When both of indices are the same forward collision probability, the AFCPI is greater than TFCPI and HFCPI.

Example 3. When $u_{TFCPI}(TTC)$ =0.6 and $u_{HFCPI}(TH)$ =0.0 then

$$u_{AFCPI}(x) = 0.6 + 0.0 - 0.6\text{x}0.0 = 0.6$$

If one of indices is 0% probability to have a forward collision then AFCPI is equal to another one.

IV. Self-Learning Algorithm

A self-learning algorithm is presented in this paper to design the points A and B in Figs. 1 and 2. Fig. 3 shows a flowchart of the forward collision warning algorithm. In Fig. 3, we have to measure the velocity of the following vehicle, V(t), and the headway time of driving car, TH(t). If the velocity of the following vehicle is greater than a setting speed, V_{set}, then it will go to execute the self-learning algorithm which is shown in Fig. 4. Otherwise, it will go to set both indices TFCPI and HFCPI as zero. Usually, we set the value V_{set}=60 km/h. After self-learning algorithm, the TTC will be calculated. The next step will check the value of TH(t).

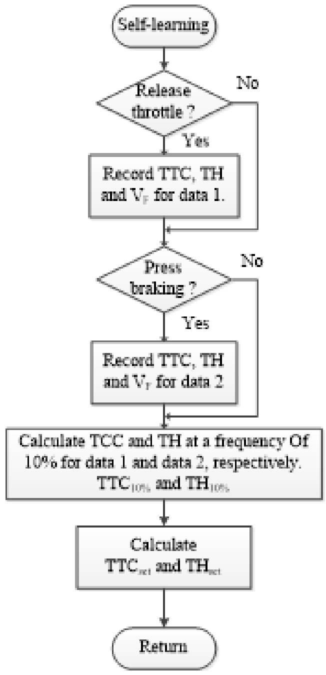

Fig. 4 A flowchart of the self-learning algorithm for the forward collision warning system

If the value of TH is smaller than $TH_{10\%}$, then it calculates the indices of TFCPI and HFCPI. Otherwise, it sets the indices of TFCPI and HFCPI to be zero. Finally, the AFCPI will be figured out and will output the warning signals or commands if necessary.

In the self-learning algorithm, as shown in Fig. 4, releasing the throttle paddle and pressing the braking paddle in high speed driving are very important for recording the driver's behavior. We record the most important parameters which are the TTC, TH, and V when driver released the throttle paddle and pressed the braking paddle. And then, we calculate TTC and TH at a frequency of 10 percent. The values of $TTC_{10\%}$ and $TH_{10\%}$ could change to any values to suit a particular driving behavior of driver. In here, we set the values as $TTC_{10\%}$ and $TH_{10\%}$ which are 10% frequency of TTC and 10% frequency of TH, respectively. Here, there are two databases which are used to record the parameters. The data 1 record the values of TTC, TH and V when driver releases the throttle paddle each time, and data 2 record the same parameters when the driver presses the braking paddle.

V. Forward Collision Warning System

The configuration of forward collision warning system based on AFCPI is shown in Fig. 5. A forward collision warning system, C2-270[24], produced by Mobileye company is used for detecting the distance between driving cars. The Mobileye C2-270 could measure the TH in real time. The message including TH(t) and $V_F(t)$ could read from C2-270 through the Controller Area Network (CAN) bus. Using TH and $V_F(t)$, we could calculate a value of D(t) which is the distance between driving cars. Based on the parameters of TH and V_F, the calculating unit could figure out the TTC. In calculating unit, the $TTC_{10\%}$ and $TH_{10\%}$ will be calculated, and the TTC_{set} and TH_{set} will be determined. Then, the forward collision probability indices TFCPI and HFCPI will be calculated. Based on the TFCPI and HFCPI, the Mamdani-type fuzzy inference system is used to evaluate the AFCPI. The driver could easily understand the index of AFCPI which is the risk of forward collision in probability.

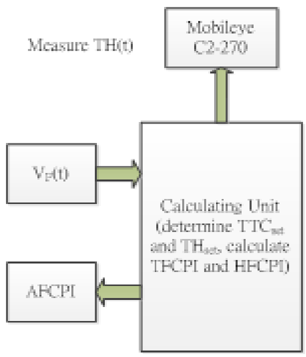

Fig. 5 The configuration of forward collision warning system based on AFCPI

VI. Experimental Results

The experimental results for guaranteed the useful of the AFCPI considering the driving behavior are presented in this section.

A. Driving Test Conditions

1. Test Car and Driver

Test car is a model named Zinger made in Taiwan. The capacity of the engine is 2,400 cc and the net weight of car is 1,690 kg. The driver is a male, 50 years old and has 30 years driving experience.

2. Test Route

Fig. 6 depicts the test route from Longtan, Taoyuan city to Xinzhuang, New Taipei city in Taiwan. The distance of test route between Longtan and Xinzhuang is 35 km. The route will drive on the Formosa Freeway and Expressway No.65 in Taiwan. During on the Formosa Freeway driving, the distance is 25 km, and speed limit is 110 km/h. The distance on Expressway driving is 10 km, and speed limits are 60 km/h and 80 km/h.

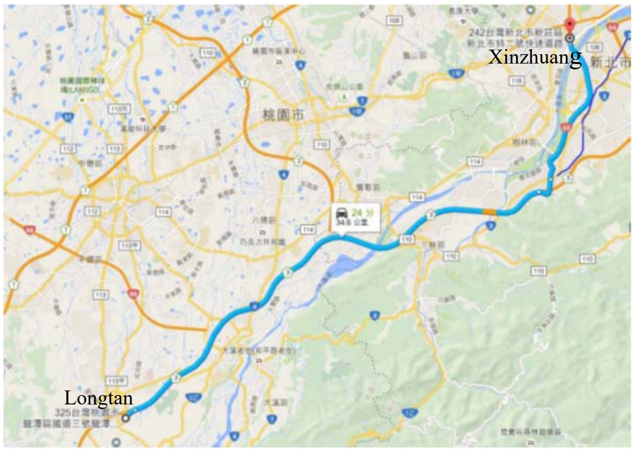

Fig. 6 The test route from Longtan, Taoyuan city to Xinzhuang, New Taipei city in Taiwan

3. Measuring Equipment

We use a forward collision warning system, the Mobileye C2-270, to measure the distance between driving cars. The Mobileye C2-270 was produced by Mobileye company. We could get the real time data including headway time, brake signal, speed and traffic sign recognition from Mobileye C2-270 through CAN bus.

B. Results of Driving Experiment

1. Design of AFCPI Display

For the AFCPI forward collision warning system, we design a friendly display for showing the AFCPI as shown in Fig. 7. From right to left, there are showing speed, TTC, TFCPI, AFCPI, HFCPI and TH. The figure displays the parameters of the driving vehicle at 16:36:20 on September 6, 2016. In Fig. 7, the speed of vehicle is 96 km/h, the TTC is greater than 8 s, TFCPI is equal to 0, the TH is 0.8 s, HFCPI is 65.28% and the AFCPI of the vehicle is 65.28%. The meaning is that 65.28% probability of forward collision may happen at that time.

Fig. 8 shows a serious TTC warning coming display. The display shows that the speed of vehicle is 96 km/h, the TTC is 0.8 s and TFCPI is 99.28%, HFCPI is 65.28%, and the AFCPI is 99.75%.

We could design the z-membership function in the beginning as shown in Fig. 9. In the beginning, we could set the points A and B for Figs. 1 and 2.

Fig. 10 shows the speed curve of the vehicle driving on highway shown in Fig. 6 for 24 minutes on September 6, 2016.

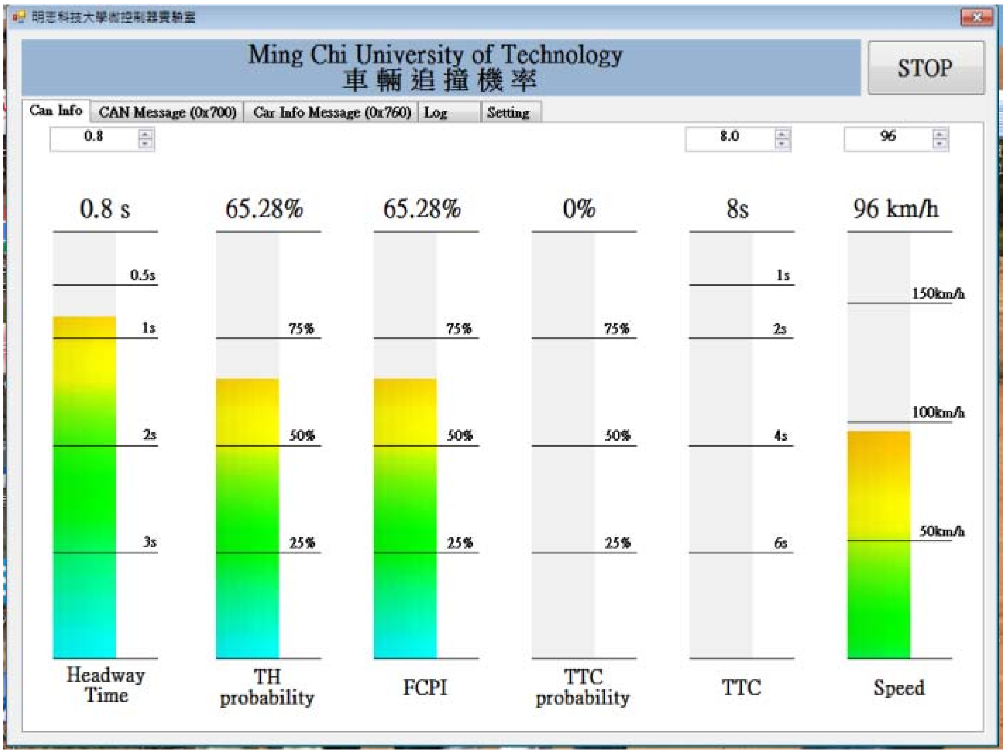

Fig. 7 Display of AFCPI forward collision warning system (2016/9/6 16:36:20)

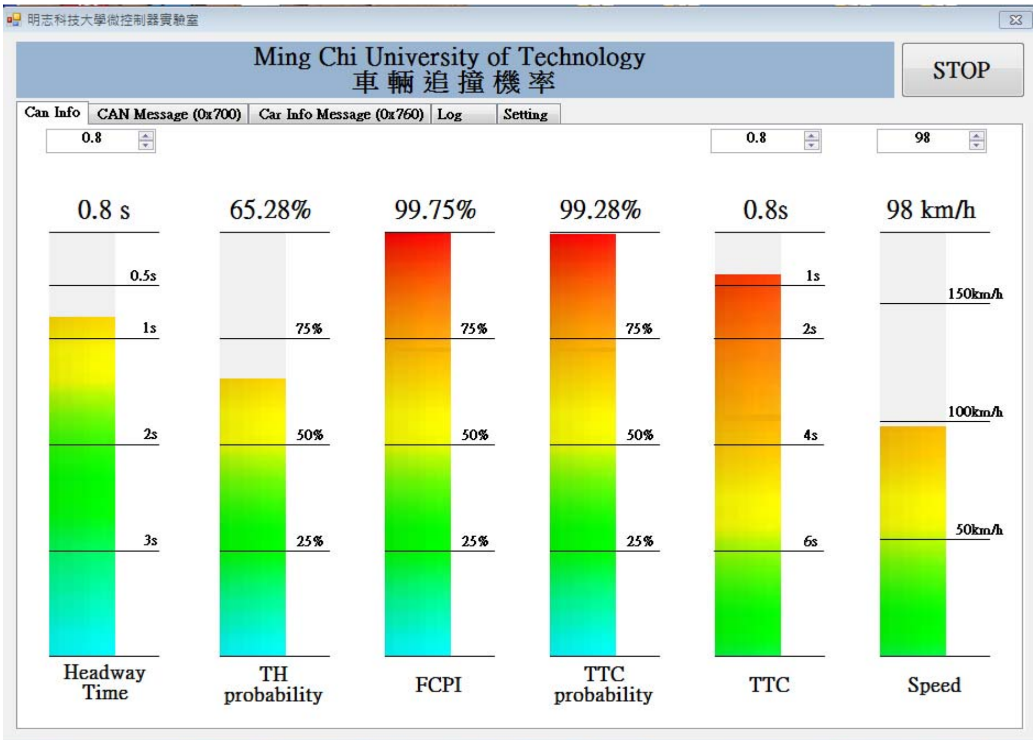

Fig. 8 Display of AFCPI forward collision warning system (2016/9/6 16:36:45)

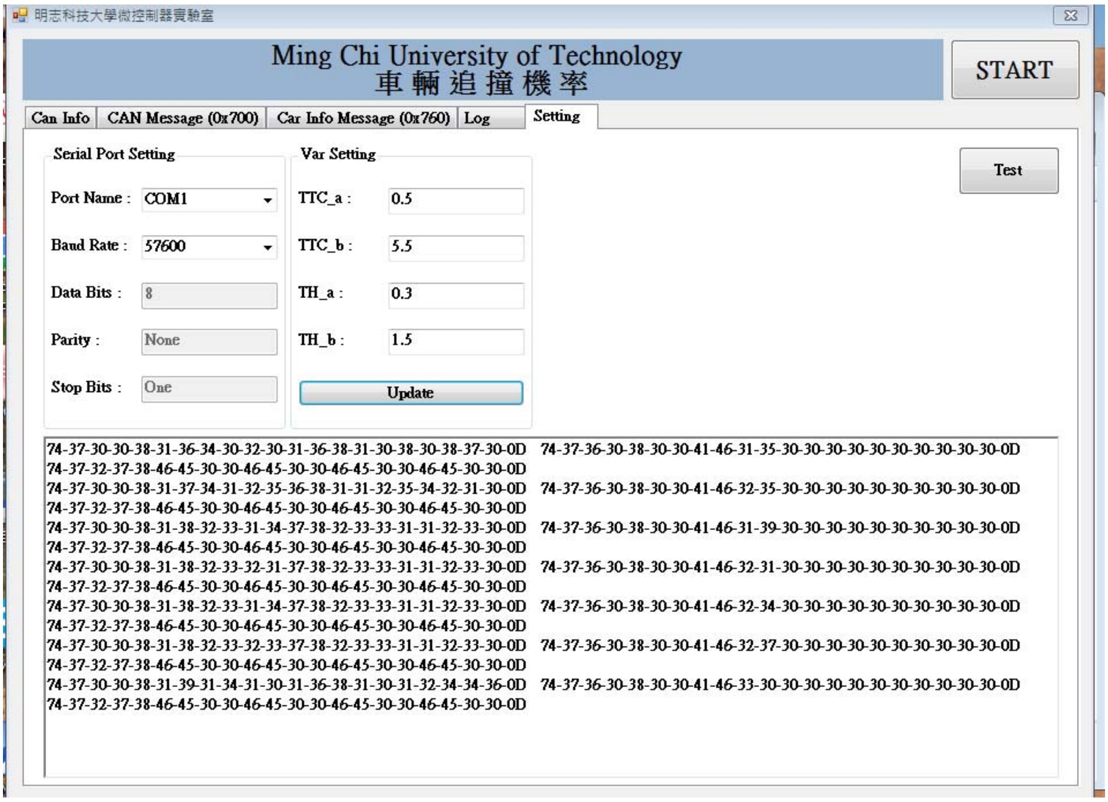

Fig. 9 Display of the z-membership function design

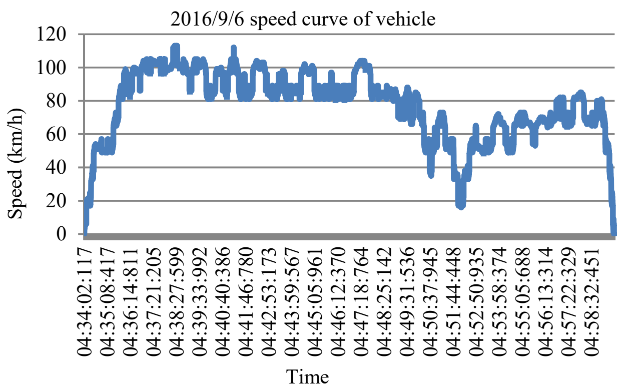

Fig. 10 Speed curve of vehicle driving on 2016/9/6

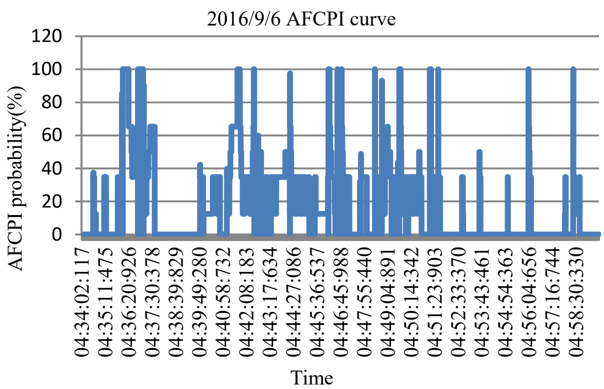

Fig. 11 Variation of AFCPI on highway driving on 2016/9/6

An approaching index variation is shown in Fig. 11 which indicated the warning forward collision probability. It is obvious that the presented AFCPI gives the total 14 times stronger warning.

The performance of using the presented AFCPI with considering the behavior of driver in forward collision warning system is guaranteed. The experimental results described that the presented method is suitable for applying in forward collision warning system in order to avoid the forward collision accident.

VII. Conclusion

An AFCPI considering the behavior of driver for forward collision warning system is presented in this paper for alerting the driver to keep the safety braking distance for avoiding the collision accident in highway driving. The presented AFCPI calculating based on the self-learning algorithm could be realized clearly by drivers even if the driver did not have any professional knowledge regarding the vehicles. The self-learning algorithm could figure out the optimal indices of TFCPI and HFCPI for the driver. The useful collision probability message can serve successfully as a safety assistance system for safer driving in highway.

Acknowledgement

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