Creating a Fuzzy Model for Stressful Driver's Behavior

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***Abstract*—A hierarchical driver_vehicle_environment fuzzy system has been proposed to analyze driver's behavior under stress conditions on a road. The stressful events can be included the interaction between driver's vehicle and the road environment or the interaction between driver's vehicle and nearby vehicles. These driving events may occur simultaneously. For obtaining fuzzy rules, experts' opinions are benefited by means of questionnaires on effects of parameters such as climate, road and car conditions on driving capabilities. Also the frequency of pressing on brake and gas pedals and the number of car's direction changes are used to determine the driver's behavior under different conditions. A fuzzy model is presented for modeling the change of steering angle and speed control by considering time distances with existing cars in these three positions, the information about the speed and direction of car, and the steering angle of car.**

***Index Terms*—Driver's behavior, stress condition, overtaking, fuzzy hierarchical modeling, decision making.**

I. Introduction

The physiological measures of the workload are based on the idea that bodily changes will be induced by a change in the workload level. Numerous studies investigating the physiological measures [including heart rate (HR), HR variability (HRV), and electroencephalogram (EEG)] have been reported in the literature [1 and its references].

To measure the physiological signals, the complex recording system should be used. For using the mentioned psychological parameter to detect human mental status while driving, it is necessary to install the measurement equipments in vehicle. Because lots of electrodes attached to driver and leads connected the electrodes to devices make the subject nervous, carrying out an experiment in real road is not only dangerous but also the result of the test is incorrect. Stress factors affecting the driver may thus arise from the vehicle and environment. Vehicle influences resulting from different driving tasks pose different demands on the driver (e.g. stabilization, maneuvering and navigation [2]). These requirements in turn depend on vehicle characteristics (e.g. acceleration, vehicle dynamics) and environmental conditions (e.g. road characteristics). In this study, we use two new parameters: the frequency of pressing on the brake and gas pedals, and the number of direction changes, to identify uniqueness in driving maneuver of each driver in different conditions. We used two levels for modeling. The low level control model is responsible for modeling the steering angle and the speed variations enforced by the driver. The high level control model, models the decision making process of the driver.

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II. Low Level Control

In order to implement the low-level control model, a simple car model is required. The car states include the Cartesian position (x,y) centered mid-way between the rear wheels and the car's orientation denoted by equations 1 to 3, where φ is the steering angle. *V* is the car's speed, θ is the angle of the car with respect to the *X* axis and *L* is the distance between centers of rear and front wheels. The equations for the car's movement in discrete form are [3]:

$$x_{n+1} = x_n + V_n \times \cos(\theta_n) \times \Delta t \quad (1)$$

$$y_{n+1} = y_n + V_n \times \sin(\theta_n) \times \Delta t \quad (2)$$

$$\theta_{n+1} = \theta_n + \frac{V_n \times \tan(\varphi_n) \times \Delta t}{L} \quad (3)$$

The speed and steering angle is updated as follows:

$$V_{n+1} = V_n + \Delta V \quad (4)$$

$$\varphi_{n+1} = \varphi_n + \Delta\varphi \quad (5)$$

The driver controls speed of car, *V*, and car's steering angle φ. In order to model the complete low level control procedure, we have assumed that apart from the information from the environment that the driver perceives, other information such as age, driver's individuality, precision and mental status are influential in the driver's control procedure.

A. Environmental Condition:

Environmental conditions are divided to three parts, the conditions of the climate, road and car. The Climate condition is the information of luminosity, range of view, rain, temperature and humidity. The Road condition is about the traffic surrounding the driver, road safety, quality of road materials, moving obstacle and having enough signs, and finally the Car condition is the information of car's ergonomic, safety equipments performance and agent of distraction in the car. The general form of fuzzy rules for climate condition, road condition and car condition are as follows:

If Range of view is … *and* Luminosity is … *and Rain* is … *and* Temperature is … *and* Humidity is … *Then* climate condition is …

If Traffic is … *and* Road quality is … *and* Sign is … *and* Moving obstacles is … *and* Safety is … *Then* Road condition is …

If Safety equipment operation is … *and* Ergonomic is … *and* Distract agent is … *Then* Car condition is …

A.1. Fuzzy rule base and membership functions:

Questionnaires have been provided to obtain the fuzzy rules, where the effects of climate, road and car condition in driving have been questioned separately. The proposed method for determining weights of parameters in fuzzy rules is as follows: First arrange the parameters. First parameter is the least important. Then a_i is assigned to i^{th} parameter such that $a_i = i \times w$. where *i* is the priority index of parameter and *w* is the priority weight which is set to 2 in this paper. When *k* parameters have equal importance, $a = w \times \frac{\sum i}{k}$ for all of *k* parameters. After that, we form the priority table ($T = [t_{ij}]$) as follows:

- If i^{th} parameter (in row *i*) is more important than the j^{th} parameter (in column *j*), then $t_{ij} = a_i - a_j$.
- If the j^{th} parameter (in column *j*) is more important than the i^{th} one (in row *i*) then $t_{ij} = \frac{1}{a_j - a_i}$
- For diagonal elements $t_{ii} = 1$

Finally the weight of each parameter, W_i, is obtained as follow:

$$W_i = \frac{M_i}{\sum_{j=1}^{m} M_j} \qquad M_i = \sqrt[m]{\prod_{j=1}^{m} t_{ij}} \tag{6}$$

where *m* represents the number of parameters. The average of the obtained weights of *n* drivers for each parameter is considered as weight of the parameter in fuzzy rules.

$$W_{parameter} = \frac{\sum_{i=1}^{n} W_i}{n} \tag{7}$$

B. Driver's Behavior:

Considering that any person is physically qualified to drive a commercial motor vehicle based on medical examination certification, the measure of more physiological parameters such as blood pressure is found in such certification data [4].We select previous record of driver's blood pressure as index of his/her natural stress status. In this study, we use two new parameters to identify driving behavior of each driver. These are frequency of pressing on the brake and gas pedals and the frequency of changing the car's direction which are affected by driver's behavior. Also the effect of environmental condition (such as climate, road and car conditions) must be considered as a driving parameter because of its effects on control of vehicle. In addition, the intelligent quality, education and precision of each person affect on estimating the distance from other vehicles or obstacles. So we consider the graduating diploma and the level of necessary precision in his/her routine job as two parameters for measuring the precision of driver. Also we consider three personalities called: risky, normal and attentive for each person. In addition, people with different ages have different reactions. Hence, also the age is taken to account in modeling of driver's behavior. The general form of fuzzy rules for coefficient of time distance with other cars, as one of the outputs of Fuzzy system *III*, is as follows:

If mental status is … *and* precision is … *and* personality is …*and* age is … *Then* time distance coefficient (K_{td}) is …

In hierarchical fuzzy system, we obtain three coefficients; first one for time distance with other cars (K_{td}), second one for the speed of car and third one for changing steering angle of car. These coefficients will affect membership functions. In proposed model, we easily have modeled the different actions under stress conditions by using the membership functions of time distance with other cars, speed of car and the steering angle of car, corresponding to each person (section3).

III. High Level Control

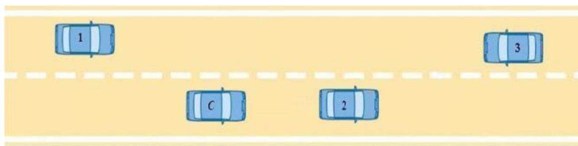
A. The Structure of Road and Effective Cars in the Decision Making of Driver

A two way road is considered for movement trajectories of cars. In the simulation, four cars are considered, the car *C* and the three important cars in decision making of driver at positions 1, 2 and 3 (Fig.1). The car *C* is the car which we intend to control it by fuzzy rules, it is called *Controlled* car. The back car which moves in opposite lane and in the same direction as *Controlled* car is called Back Same Direction Opposite Lane (*BSDOL*) car (Fig 1, position 1). If the front car in opposite lane moves in the same direction as *Controlled* car, then it is called Front Same Direction Opposite Lane (*FSDOL*) car (Fig1b, position 3) and if its movement direction is opposite to *Controlled* car then it is called Front Opposite Direction Opposite Lane (*FODOL*) car (Fig1a, position 3). If the front car in the same lane of *Controlled* car moves in the same direction as *controlled* car then it is called Front Same Direction Same Lane (*FSDSL*) car (Fig1a, position 2) and if it is in opposite direction then it is called Front Opposite Direction Same Lane (*FODSL*) car (Fig1b, position 2).

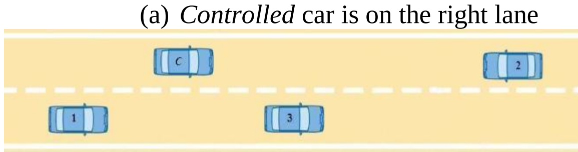
B. Decision Making Process:

In this model, the general form of fuzzy rules is as follows:

Rule i: If Td_{BSDOL} *is … and* Td_{FSL} *is … and* Td_{FOL} *is …and V is …and Dir is … and* φ *is … Then* Δv *is …and* $\Delta\varphi$ *is …*



(a) *Controlled* car is on the right lane



(b) *Controlled* car is on the left lane

Fig. 1. The situations of important cars in the decision making of driver

where Td_{BSDOL} is the time distance of *Controlled* car with *BSDOL* car, Td_{FSL} is the time distance with the front car moving in the same lane (*FSDSL* or *FODSL* car), Td_{FOL} is the time distance with the car which is moving in the opposite lane (*FSDOL* or *FODOL* car), *V* is the speed of *Controlled* car, *Dir* is the moving direction of *Controlled* car and φ is its steering angle. These are input variables of fuzzy rules. The output variables are the change of speed and changing on direction of steering. Each of the input variables Td_{BSDOL}, Td_{FSL} and Td_{FOL} has four linguistic terms: *very low*, *low*, *medium* and *high*. In fuzzy rules we have:

$$Td_{FSL} = \begin{cases} Td_{FSDSL}, & \text{if } FSDSL \text{ exist} \\ Td_{FODSL}, & \text{if } FODSL \text{ exist} \end{cases}$$

$$Td_{FOL} = \begin{cases} Td_{FSDOL}, & \text{if } FSDOL \text{ exist} \\ Td_{FODOL}, & \text{if } FODOL \text{ exist} \end{cases}$$

The speed has three linguistic terms: *low*, *medium* and *high*. The car direction and the steering angle direction have five linguistic terms (*very right*, *right*, *not change*, *left* and *very left*).

- **The membership function of time distance with other cars**

The membership function of time distance with other cars is defined for a *normal* driver who drives according to driving laws. In all of membership functions of time distance with other cars, three points of membership functions are important:

- The point where the membership of second linguistic term (*low*) begins to increase from zero. It is called P_1.
- The point of second linguistic term (*low*) at which the membership returns to zero. It is called P_2.
- The point of third linguistic term (*medium*) at which the membership returns to zero. It is called P_3.

We formed the time distance vector as: Vec_{td}.=[P_1 P_2 P_3]. For modeling different behaviors of driver, we apply the coefficient for time distance vector, K_{td} , obtained by hierarchical fuzzy system.

After obtaining Vec_{td} with other cars, we have:

$$\mu_{very low\ or\ high}(x) = \max[\min(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}), 0] \quad (8)$$

$$\mu_{low\ or\ medium}(x) = \max[\min(\frac{x-a}{b-a}, \frac{c-x}{c-b}), 0] \quad (9)$$

- **The membership function of steering angle and direction of car**

The car direction and the steering angle direction have five linguistic terms (*very right*, *right*, *not change*, *left* and *very left*). The coefficients (a, b, c, d) of membership functions which are obtained by Eqs. (8) and (9) are represented in table 1.

TABLE I: COEFFICIENTS OF FUZZY MEMBERSHIP FUNCTIONS FOR STEERING ANGLE AND DIRECTION OF CAR

Linguistic terms	a	b	c	d
very right	*Center(1)*	*Center(1)*	*Center(1) +D*	*Center(2)*
right	*Center(1) +D*	*Center(2)+1 .3D*	*Center(3)*	-
zero (direction)	*Center(3) -0.3D*	*Center(3)*	*Center(3) +0.3D*	-
zero (steering angle)	*Center(3) -0.2D*	*Center(3)*	*Center(3) +0.2D*	-
left	*Center(3)*	*Center(4)-1. 3D*	*Center(5) -D*	-
very left	*Center(4)*	*Center(5)-D*	*Center(5)*	*Center(5)*

In which :

$$Center(i) = \frac{(DS_{F_n} - DS_{I_n}) \times (i-1)}{N_{ling} - 1} + DS_{I_n}$$

$$D = 5 \qquad N_{ling} = 5$$

DS_{Fn} is final point and DS_{In} is initial point of universes for steering angle and direction of car for *normal* driver.

$$DS_{I_n} = -50^{\deg} \qquad DS_{F_n} = 50^{\deg}$$

B.1. Road partitions in decision making of driver:

Drivers drive in different positions of road. We divide the road to four divisions: *Left lane*, *Middle lane*, *Right lane* and *Shoulder of road lane*. When a driver intends to pass the leading car, he/she moves toward *Middle lane*. In low speed and dangerous conditions, the car moves toward the shoulder of road. So among four decision lanes, *Middle lane* and *Shoulder of road lane* are transient lanes. A driver is driving in the right lane and he/she drives in the left lane only when he/she is passing the leading car. Safety and speed satisfaction are two main factors which have been considered as goals from the driver's perspective, influencing his/her decision making and are included in driver's behavior modeling, depending on his/her age and personality.

B.2. Fuzzy rule base in decision making of driver:

By considering the above goals, the decision making process is categorized into four scenarios:

1) *Right lane*

- Staying in the same lane and continuing the path

a) No car is in front. The car continues its path.

b) A car is in front and the time distance with it is low, the driver starts to make a decision based on his/her desired speed and safety priorities but *FODOL* car is near or there is a *BSDOL* car, then the driver decreases the speed of car and continues the path.

- Going to shoulder of road

a) A car is in front and the time distance with it is very low but both *FODOL* and *BSDOL* cars are near. So she/he can't overtake. In order to avoid collision, the driver must move the car to the shoulder of road.

b) The time distance with *FODOL* car is low and *FODSL* is passing it. In this condition, the driver must move the car toward the shoulder of road.

- Going to *Middle lane* for passing

When the driver decides to change lane and overtake, he/she moves the car to *Middle lane*.

2) *Middle lane*

As mentioned before, this lane is a transient lane. If conditions are satisfied, the driver increases the speed and continues with the same direction to enter the left lane to overtake. Otherwise he/she decides to stay in *Middle lane* or to return to *Right lane*.

After overtaking, if the return conditions are satisfied, driver enters from this lane to *Right lane* with the same speed. Otherwise he/she stays in this lane until providing the return conditions.

3) *Left lane*

- Before taking over

If conditions are satisfied, the driver continues the path with high speed. Otherwise he/she goes to *Middle lane* and decides to stay there until conditions are provided or he/she returns to *Right lane*.

- After overtaking

The driver goes from this lane to *Middle lane* with the same speed in order to go to *Right lane*.

4) *Shoulder of road lane*

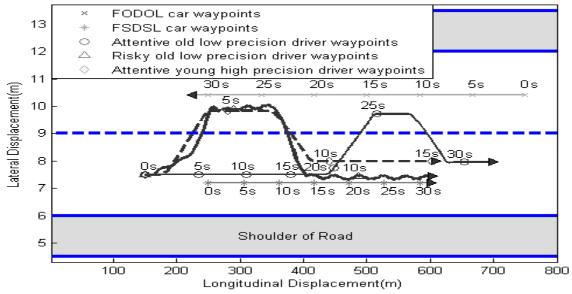
As mentioned before, the driver goes to this lane to avoid collision. So he/she must stay in this lane until he/she could return.

IV. Results

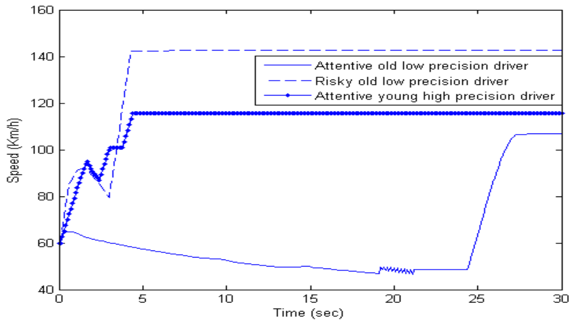
The obtained weights of questionnaires for each of environmental parameters from eq. (7) are summarized in Table 2. We consider intending driver to pass the leading car as a stress condition. In following, the human behavior in driving under mentioned stress conditions are investigated. Two strategies for the *Controlled* car are considered: (1) *Controlled* car must wait until *FODOL* car passes then it overtakes, (2) it has enough time to pass the leading car. In stress condition, we compare behaviors of three drivers (An attentive old driver and a risky old driver with very low precision; an attentive young driver with very high precision) under same overtaking conditions (Fig. 2). As it is shown in Fig. 2-a, the risky old driver with low precision and attentive young driver with very high precision pass the leading car. But attentive old driver with very low precision waits until the *FODOL* car passes and then he/she passes the leading car. The very low precision person's error is higher than that of the very high precision person in estimating distance with other car. Because of being attentive, the old driver waits for passing the leading car to collision avoidance. The car's speed (Fig. 2-b) of each driver shows the driver's behavior and decision under equal conditions. The risky old driver and attentive young driver increases the speed to overtake (at time 0^{sec} of simulation) and goes to the middle lane (Fig 2-a). The movement of attentive young driver is smooth. The risky old person with very low precision has more steering direction change and earlier than the young person begins to passing and return to the right lane because he/she is risky and old. The attentive old person with very low precision is late in decision making. He/she waits considerably long time, then passes the leading car (at time 18^{sec}) and returns the right lane as soon as possible (at time 29^{sec}), because of his/her attentive characteristic. Because of having less speed, the attentive old driver needs more time of passing than the young driver and risky old driver.

TABLE II: The Weights of Environmental Parameters in Fuzzy Rules

		Weight
Climate parameters	Range of view	0.37
	Luminosity	0.297
	Rain	0.178
	Temperature	0.098
	Humidity	0.057
Road parameters	Traffic	0.21
	Road quality	0.13
	Sign	0.11
	Moving obstacle	0.21
	Safety	0.34
Car parameters	Equipment operation	0.47
	Ergonomic	0.25
	Distract agents	0.28



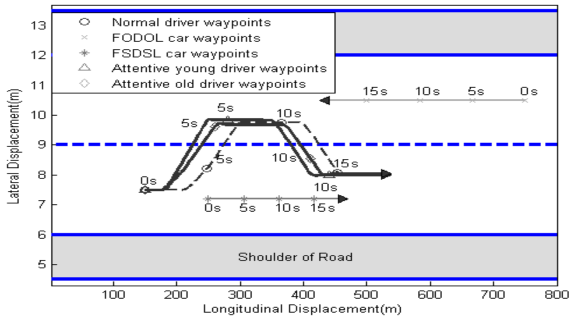
a) Passing the leading car by different drivers



b) The speeds of cars by different drivers

Fig. 2. The comparison of different driving behavior in equal conditions

In Fig 3, the behavior of different drivers, when *Controlled* car has enough time to pass the leading car, are compared. In simulation, three drivers (*Normal* driver, an attentive young driver and an attentive old driver) are considered. The obtained results show that the old driver and young driver earlier than *Normal* driver begin to passing and return to the right lane because of being attentive. The old person needs more time of passing than the young person. But both them increase the speed of car (Fig 3-b) and need less time than *Normal* driver to pass because of having the high speed.



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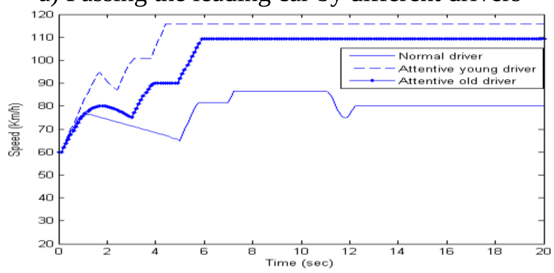

b) The speeds of cars by different drivers

Fig. 3. The comparison of different driving behavior in equal conditions

V. Conclusion

We used two levels for controlling of car. The fuzzified three positions model has been presented for low-level control and a fuzzy hierarchical system was proposed for high-level control. In the high level control model, the fuzzy hierarchical system is used for modeling of driver's behavior. We consider overtaking stress conditions. The different drivers' behavior under mentioned stress conditions are investigated.

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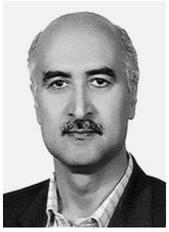

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